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AUTOMATIC IONOSPHERIC PARAMETER EXTRACTION FROM DIGITAL IONOGRA--ETC(U)
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The development of techniques to automatically extract the ionospheric ionization parameters of foF2, M(3000), fmin, and ftEs from digital ionograms have become feasible with the advent of advanced digital sounders. From digital ionogram data of the Digisonde 128PS the six most significant echoes for each frequency are extracted in the Geomonitor. They are further processed in the Automatic Parameter Evaluation program (A.P.E.) to deter-

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mine the main echo height for each frequency. The program takes into consideration the frequency continuity of the reflection height, multiple hop reflection heights, rate of change of slope and the physical properties of the ionogram such as foE's dependence on the solar zenith angle. The output data are mathematically smoothed to produce a refined ionogram. From this refined ionogram the A.P.E. program determines the four ionospheric parameters. In a study of 1500 ionograms the automatically evaluated ionogram parameters are compared with the manually scaled values and the differences are analyzed statistically. Also some case studies are discussed concentrating on the reasons for larger deviations. The program has been written considering the future possibility of implementation in a microcomputer which can integrate the functions of the Geomonitor, as well as a True Height Analysis program.

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1.0 INTRODUCTION

Hardware and software algorithms for the automatic processing of Digisonde ionograms were developed by one of the authors (B. W. Reinisch) beginning in 1970 (Bibl and Reinisch, 1972; Bibl et al, 1973). Cormier and Dieter (1974) developed a computer program that extracted ionospheric parameters from Digisonde ionograms recorded on magnetic tape. This program was not organized with regard to later real time application.

For over two years the Geomonitor microcomputer system (Reinisch and Smith, 1976) has been processing on-line digital ionograms from a Digisonde 128 (Bibl et al, 1970) at the U.S. Air Force Geophysics Laboratory (AFGL) ionospheric station in Goose Bay, Labrador. The Geomonitor employs a six-echo identification algorithm on each operating frequency. Virtual height, logarithmic amplitude and range spread information for each frequency is formatted onto 7-track magnetic tape. This preprocessed data is used as input to the FORTRAN Automatic Parameter Evaluation program (A.P.E.).

In the A.P.E. program the ionograms are further processed to extract several ionospheric parameters: foF2, MUF(3000), M(3000), ftEs and fmin, following the definitions of the International Radio Science Union (URSI). Definitions and procedures for the scaling of ionograms were developed by Bibl et al (1955) and had been adopted by URSI and are described by Piggott and Rawer (1961). Later revisions can be found in Piggott and Rawer (1972) and the High Latitude Supplement (1975). The Geomonitor data are corrected for multiple hop echo ambiguity, inconsistencies created by noise interference, and extraordinary trace interference. Finally a three-point smoothing method is applied and critical frequencies are extracted taking into consideration reasonable limits for the change of height as a function of frequency.

The A.P.E. program is written as simply as possible to facilitate its translation into a microcomputer program for real time conversion of ionograms into scaled parameters. As a by-product of the A.P.E. program the refined ionogram trace defines the input data for automatic true height calculations.

2.0 THE A.P.E. ALGORITHM

Before explaining the procedure and evaluation carried out by the A.P.E. program it is first necessary to describe the Geomonitor and Digisonde data.

For each transmitting frequency the Digisonde sends the logarithmic amplitudes for 128 specific height bins to the Geomonitor. This data is processed in the Geomonitor, independently on each frequency, with no consistency checks between adjacent frequencies. The 128 height bins are divided into two ranges: E region < 156 km and F region $\geq$ 156 km. For each frequency, up to two significant echoes are found in the E region and four in the F region. Figure 1 shows two consecutive ionograms, the one on the left is a Digisonde "raw" ionogram and on the right a Geomonitor "reconstituted" ionogram. By recording on tape the amplitudes and ranges of the identified echoes the data volume is reduced by a factor of ten with little loss of significant echoes. The data information for each frequency is packed in seventeen six-bit words which describe 16 parameters: N, G, AE1, AE2, AF1, AF2, AF3, AF4, HE1, HE2, HF1, HF2, HF3, HF4, DE, DF. N is the noise threshold in dB defined as the positive half point of the amplitude distribution. G is the relative attenuation (or negative gain) of the receiver in 10 dB increments for the specific frequency. AE and AF are the amplitudes in dB of the E and F region echoes. The two E echoes and four F echoes are sorted in descending order of magnitude. HE1 refers to the virtual height (range) of the echo whose amplitude is AE1. DE and DF are the spreads in range of the primary echoes (E1 and F1). A more detailed explanation of the techniques used to reduce Digisonde raw ionograms to Geomonitor output data is given in "Geomonitor - Digital Real Time Processor for Geophysical Data" (Reinisch and Smith, 1976).

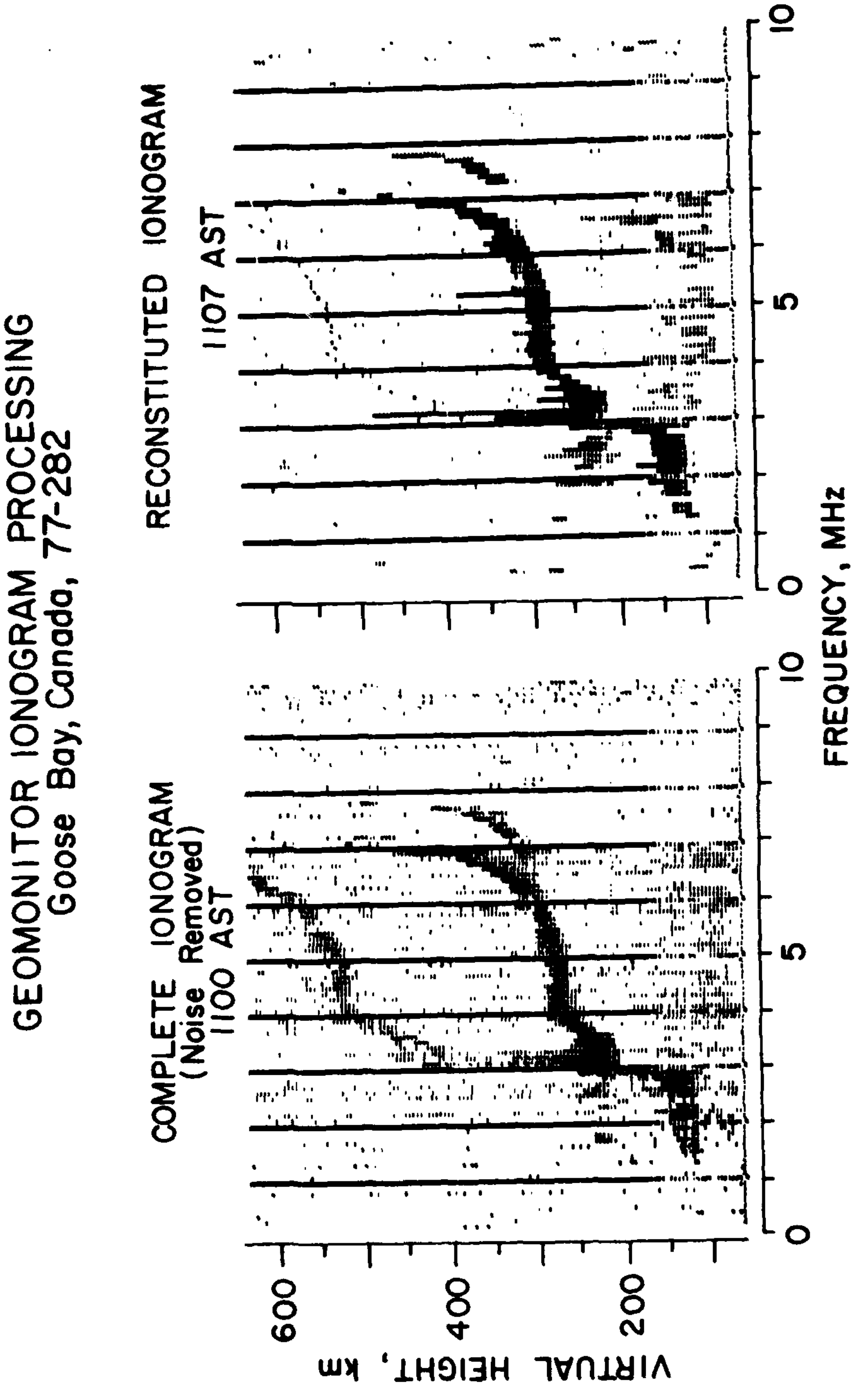

GEOMONITOR IONOGRAM PROCESSING
Goose Bay, Canada, 77-282
COMPLETE IONOGRAM
(Noise Removed)
1100 AST
RECONSTITUTED IONOGRAM
1107 AST
VIRTUAL HEIGHT, km
600
400
200
0
5
10
0
5
10
FREQUENCY, MHz

FIGURE 1

During the period from November 1976 to June 1978 the Geomonitor was connected to the Digisonde 128. After this period a new Digisonde 128PS (Bibl and Reinisch, 1978a and 1978b) was installed in Goose Bay. The main difference between the two data sets is the suppression of echoes with extraordinary polarization in the 128PS data. Therefore the algorithm to determine foF2 is simplified for the new data. In this report the algorithms for both data sets will be discussed.

Beginning at frequency fn equal to foE a smooth F trace is assembled. To start the trace the first step is the determination of fminF. This is normally equal to foE except at night or when significant absorption occurs. Monthly median values for foE are provided as an input to the program.

2.1 Smoothing of F-Traces and foF2 Determination

The following logic steps are executed to determine a single value for height and amplitude at each frequency in the F region:

1. Eliminate all HF1(I) for I < fminF.
2. HF(I) = HF1(I).
3. If HF1(I) = 2*HF2(I) ±10 km it is assumed HF1(I) is the second hop reflection and HF(I) = HF2(I).
4. If HF(I) = 2*HF(I-1) ±10 km, HF(I) = 1/2 HF(I).
5. If a data point is missing between two adjacent non-zero data, i.e. HF(I) = 0 and HF(I-1) ≠ 0 and HF(I+1) ≠ 0, then an interpolated value is placed in HF(I). HF(I) = (HF(I-1) + HF(I+1))/2.
6. A sliding three-point smoothing method is applied. This algorithm simultaneously checks for negative values of the deviation of h'(f) from the two successive echoes and eliminates all data points to the right of a fast drop in echo height.

Figure 2a shows a computer output of the HE, HF, AE, AF as reconstituted from the Geomonitor output tape. The noticeable difference from the Geomonitor Versatec output (Fig. 1) is the absence of the echo spread. For the time being we consider the leading edge of the echo trace as characteristic for the vertical echo. Hence there is no need to display the spread. This approach will lead to disagreement with the URSI definition of foF2, which is read as the inner edge of the trace in the presence of spread. This problem will be treated later.

Figure 2b shows the F-region of the ionogram after steps 1 and 2 are completed. Note the double echo reflections at 6 and 6.7 MHz. Short bite-outs in single echo amplitudes indicate interference fadings of two polarization modes with the same delay. After performing the double echo elimination and linear interpolation (steps 3-5), we arrive at the ionogram in Figure 3a. Figure 3b is the final F region refined ionogram after the three-point smoothing method is applied and the critical frequency is determined.

An overall flow diagram of the three-point smoothing method is shown in Figure 4. Since we combine the search for fc (the critical frequency) with the smoothing of the data, the flow diagram seems to be complicated. Figure 5 describes just the smoothing of the data assuming the fmin of the F-layer trace is found. The variables which are system related are ITEST, IDROP and MINFRQ.

ITEST is the greatest difference in range for adjacent frequencies allowable at specific height ranges

$60 \leq h' < 156$ km	ITEST = 18 km
$156 \leq h' \leq 350$ km	ITEST = 33 km
$350 < h'$	ITEST = 70 km

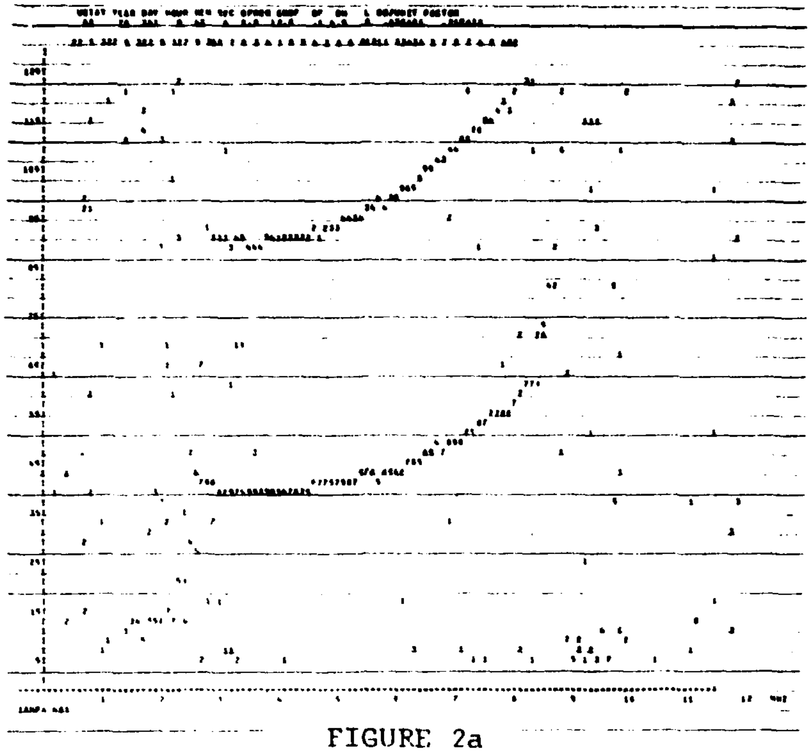


FIGURE 2a

RECONSTITUTED IONOGRAM E1,E2,F1,F2

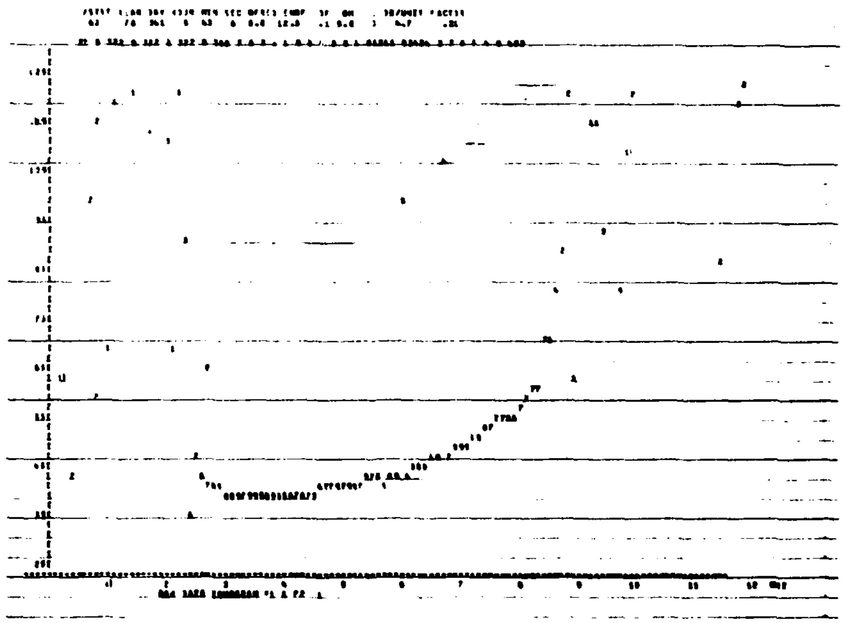


FIGURE 2b

RECONSTITUTED IONOGRAM F1

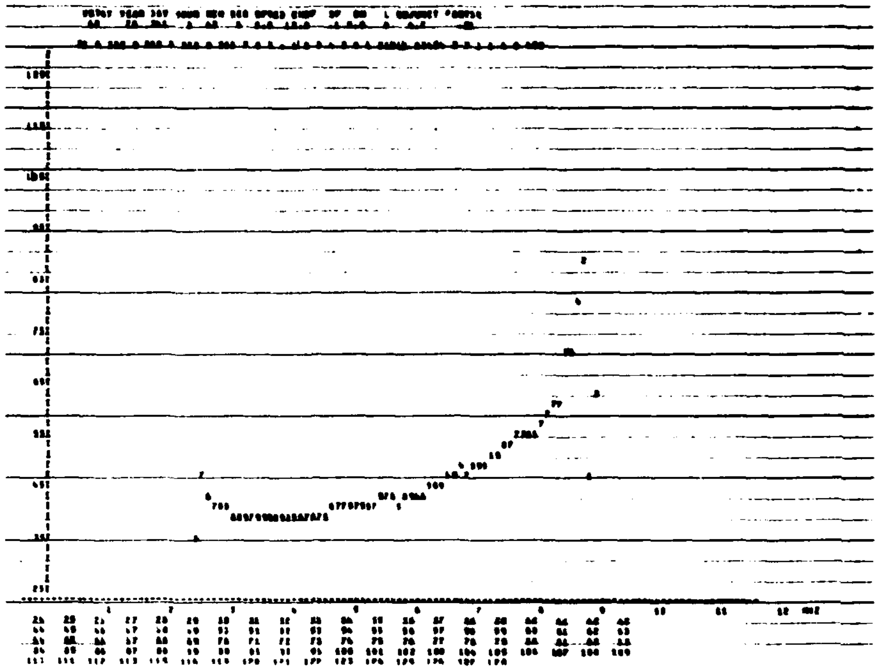


FIGURE 3a **PARTIALLY PROCESSED**

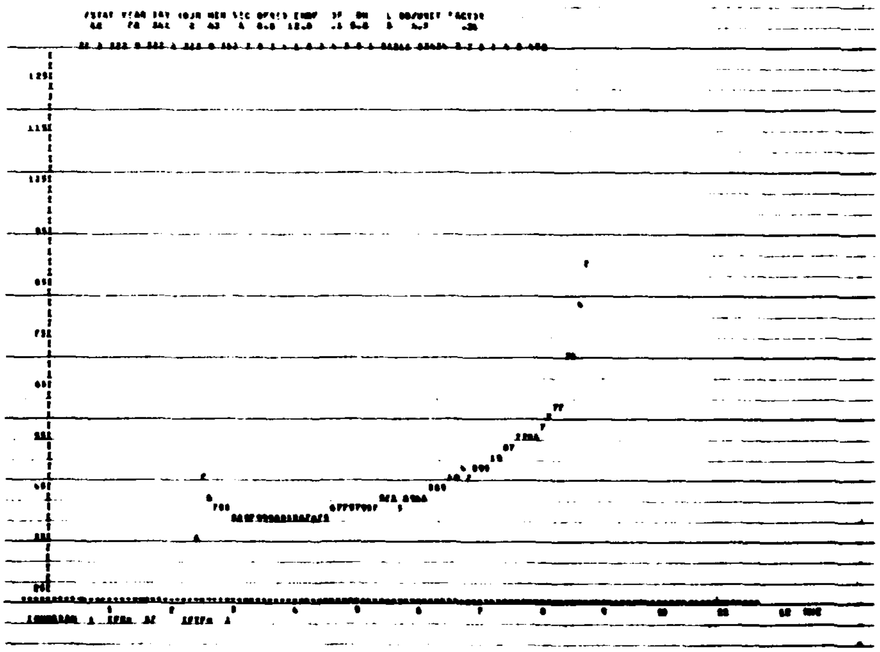


FIGURE 3b **REFINED IONOGRAM**

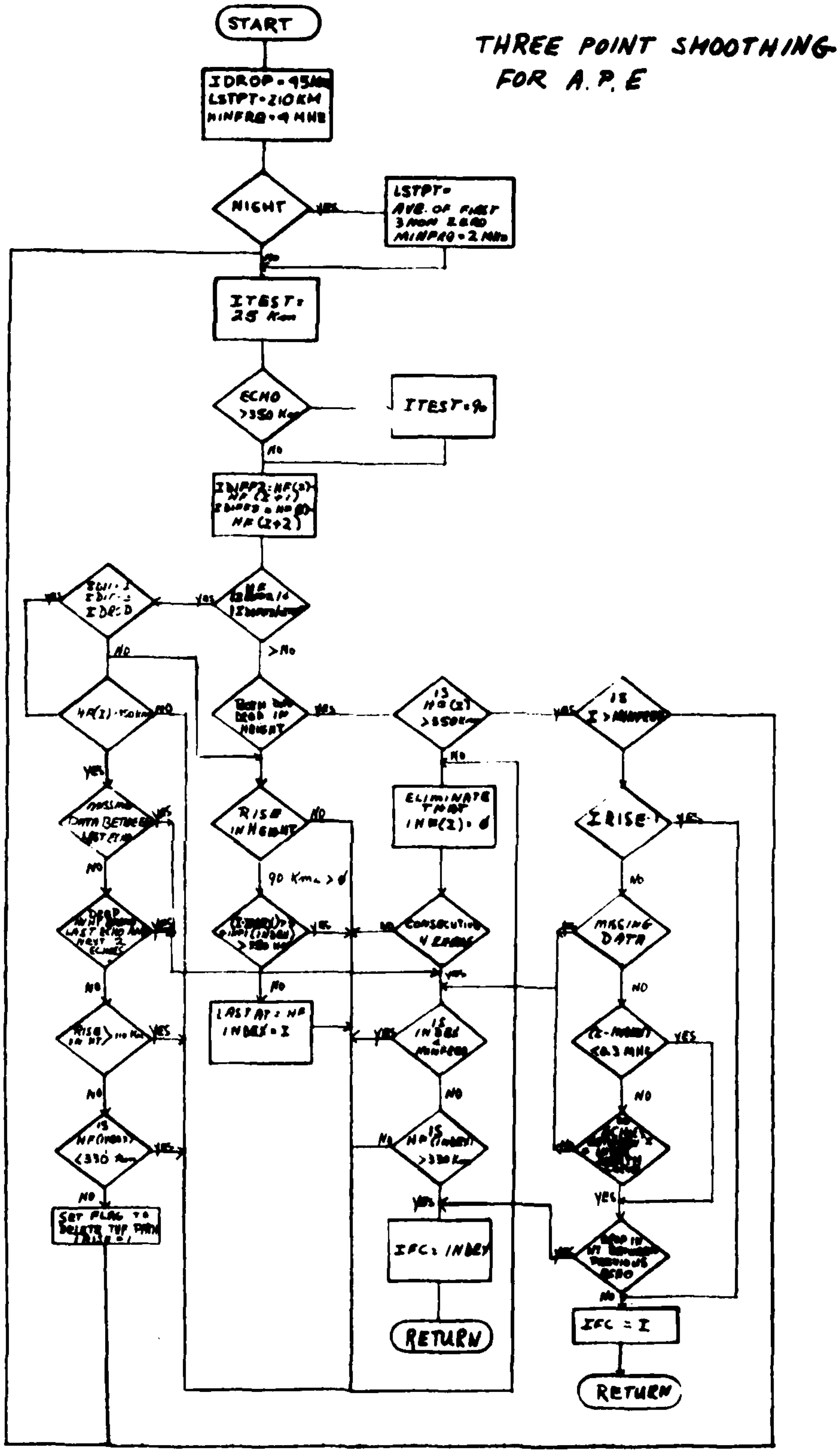
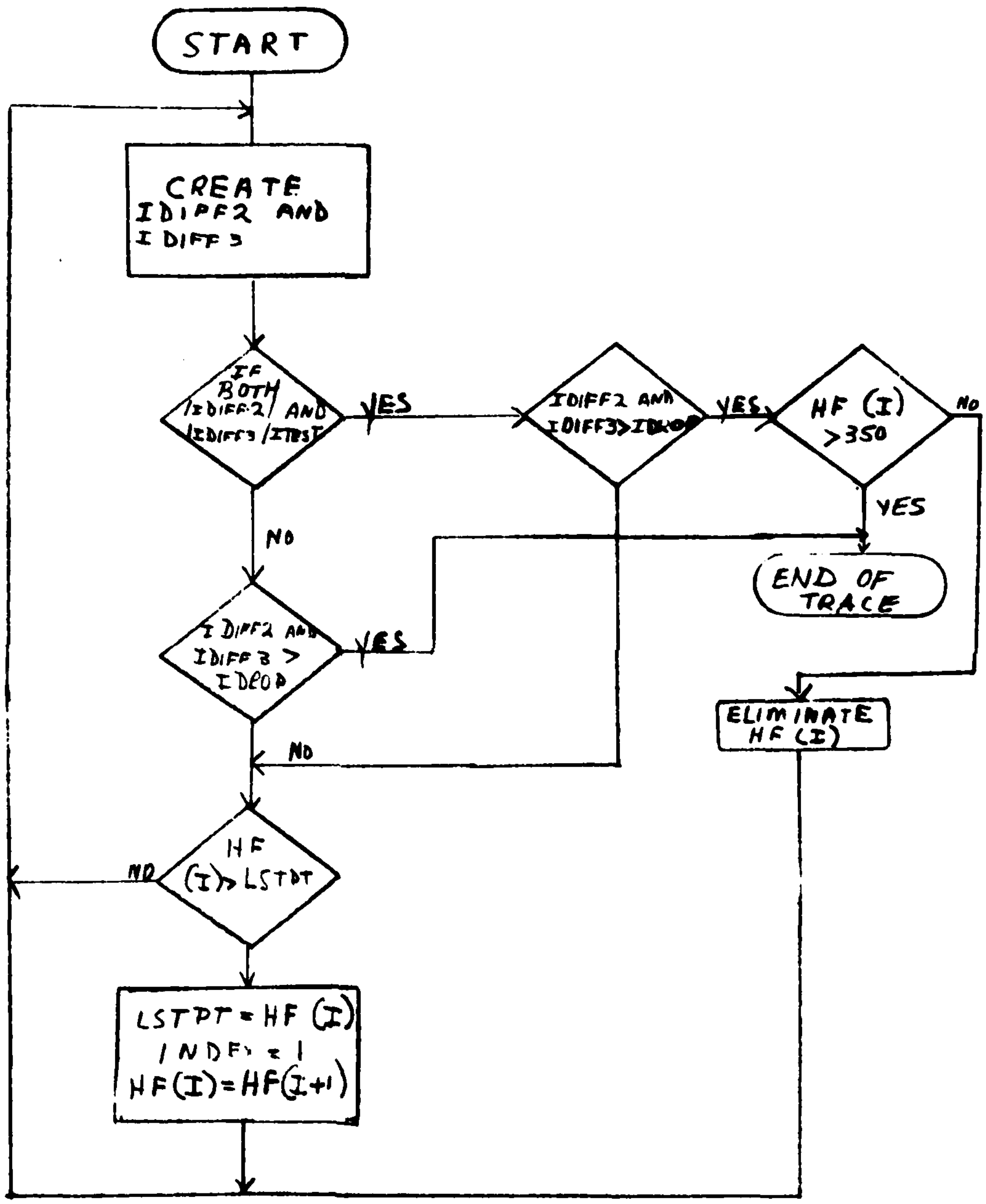


FIGURE 4



THREE-POINT SMOOTHING FLOW CHART

FIGURE 5

IDROP is the greatest allowable drop in height for consecutive frequencies. At the retardation frequency between E and F, and F1 and F2 we must permit a small consistent drop in height to accommodate the decrease in retardation with increasing frequency caused by the thick E- or F1-layers: IDROP $\leq$ 45 km.

IDROP is used to eliminate any drastically inconsistent data and primarily to eliminate the extraordinary trace when a significant drop in height from the O to X-echoes is detected as it occurs near the critical frequency. Since the ionogram is scaled from minimum to maximum electron density the ordinary trace information will precede the X-trace. The ionograms from the 128PS system have X-echo suppression and the drop-in-height criteria used to recognize foF2 is less useful since the data points following the foF2 are noise rather than the predictable X trace.

LSTPT is the height of the last virtual height with positive slope. LSTPT is preset to 210 km for daytime ionograms. For the night ionograms LSTPT is the average height of the first three non-zero F region echoes.

MINFRQ is the minimum frequency acceptable for foF2:

MINFRQ in the day = 4 MHz

MINFRQ at night = 2 MHz.

The time between hours 8 to 20 is defined as daytime. These empirical values are valid for the Goose Bay ionograms.

2.1.1 MUF(3000) and M(3000) Determination

The maximum usable frequency for oblique transmission over a distance of 3000 km is designated MUF(3000). The corresponding M(3000)-factor is determined by dividing MUF(3000) by the critical frequency of the reflecting layer.

In principal, the MUF can be calculated if the vertical electron density and the horizontal gradients in ionization are known. Since this is generally not the case certain approximations must be made.

Starting with Bouguer's law of refraction for spherical geometry (Reinisch, 1969):

$$n_R R \sin \phi_R = R_0 \sin \phi_0$$

(n = index of refraction; R = length of radius vector from center of earth, ϕ = angle between radius vector and ray; R_0, ϕ_0 = values at transmitter location), and using the no-magnetic field approximation for the index of refraction

$$n_R^2 = 1 - (f_P(R)/f)^2$$

($f_P(R) = f_{VERT}$ reflected at height R), one arrives at the relation (with $f = f_{ob}$):

$$f_{ob} = f_V \sec \phi_R.$$

Spherically (or at least cylindrically) symmetric ionization was assumed in obtaining the last equation. ϕ_R is the angle that the extended take-off ray forms with the radius vector at radius R, defining the height of reflection (Bibl, 1950). Of course, ϕ_R is not known for an arbitrary profile.

For a stratified plane ionosphere f_{ob} can easily be calculated using the equivalent path theorem of Breit and Tuve (1926):

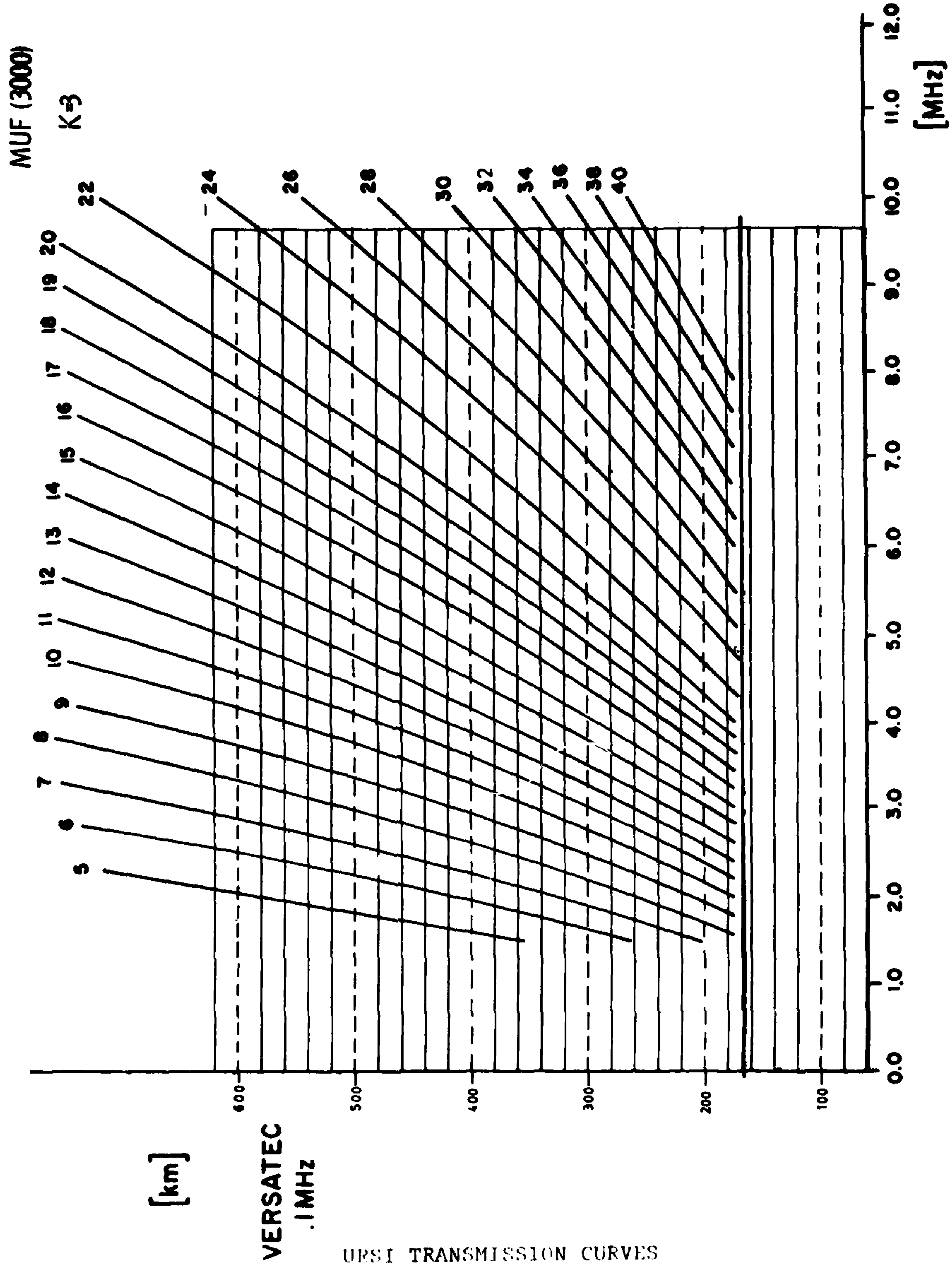
$$f_{ob} = f_V \sqrt{1 + (D/2h')^2}$$

where D is the distance between transmitter and receiver, and h' the virtual height of reflection of the frequency f_V. This relation between f_{ob} and f_V suggests the general translational equation

$$f_{ob} = M(h') \cdot f_V$$

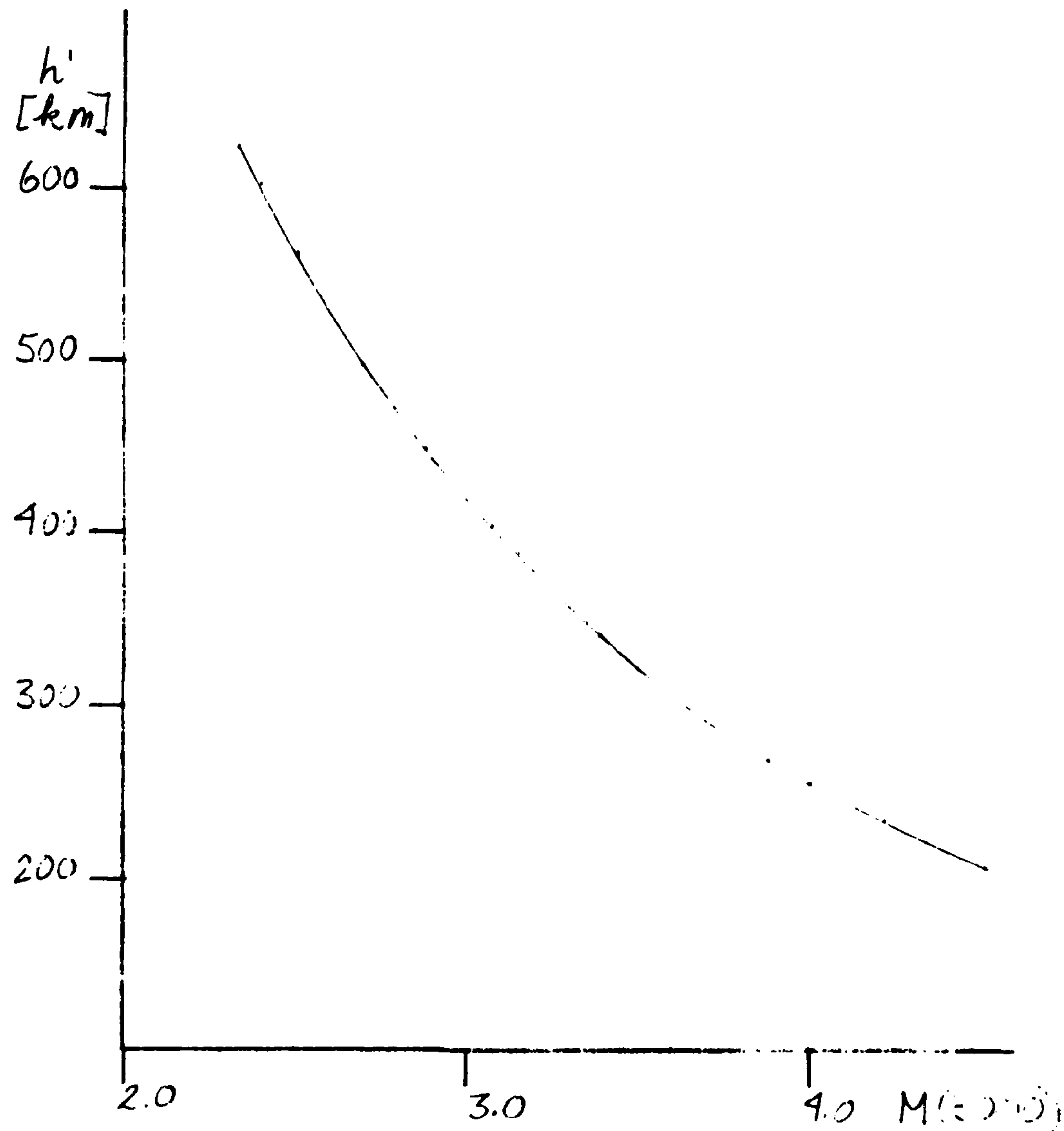
for curved geometry. A semi-empirical transmission curve M(h') was introduced by Smith (1939). Bibl (1956, 1960) used an exponential function for automatic transformation of vertical analog ionograms to MUF, recording the MUF in real time. Manual ionogram scalers use a set of transmission curves to graphically solve for MUF. The URSI 3000 km standard transmission curves are shown in Figure 6, and the corresponding M(h') curve is given in Figure 7. Appendix C lists M(h') for h' from 181.5 to 636 km in steps of 2.25 km; the Geomonitor outputs the data in 2.25 km steps. To enable comparison between manually scaled and A.P.E. calculated MUF values it was decided to use the URSI transmission curves in the A.P.E. algorithm. Once M(h') is given it is very easy to calculate from the vertical ionogram the corresponding oblique ionogram. This transformation is shown in Figure 8. It seems to be easy now to determine MUF as the largest reflected frequency in the oblique ionogram. Principally one could also use the manual scaling method by comparing the ionogram trace with the set of transmission curves shown in Figure 6 and finding the one that is tangent to the h'(f) curve (Cormier and Dieter, 1974). This approach was eliminated due to its sensitivity with regard to erroneous data points and the substantial calculation requirements.

One can see from Figure 8 that the density of data points in the oblique ionogram is highest near MUF. This fact can conveniently be used to determine MUF. We count the number of data points within each one half MHz band. To reduce the effect of erroneous data points which quite often have a small amplitude, we perform an amplitude-weighted number count by forming the sum over the logarithmic amplitudes within each interval. While from the horizontal part of the F-trace in the vertical ionogram only one or two data points are imaged into a one-half MHz band of the corresponding oblique ionogram, there will be about five points per interval in the MUF-region. Because the amplitudes of the vertical ionogram are in general relatively strong around the frequencies corresponding to MUF



URSI TRANSMISSION CURVES

FIGURE 6



h' VERSUS M(3000)

DERIVED FROM URSI STANDARD 3000 km TRANSMISSION CURVES

FIGURE 7

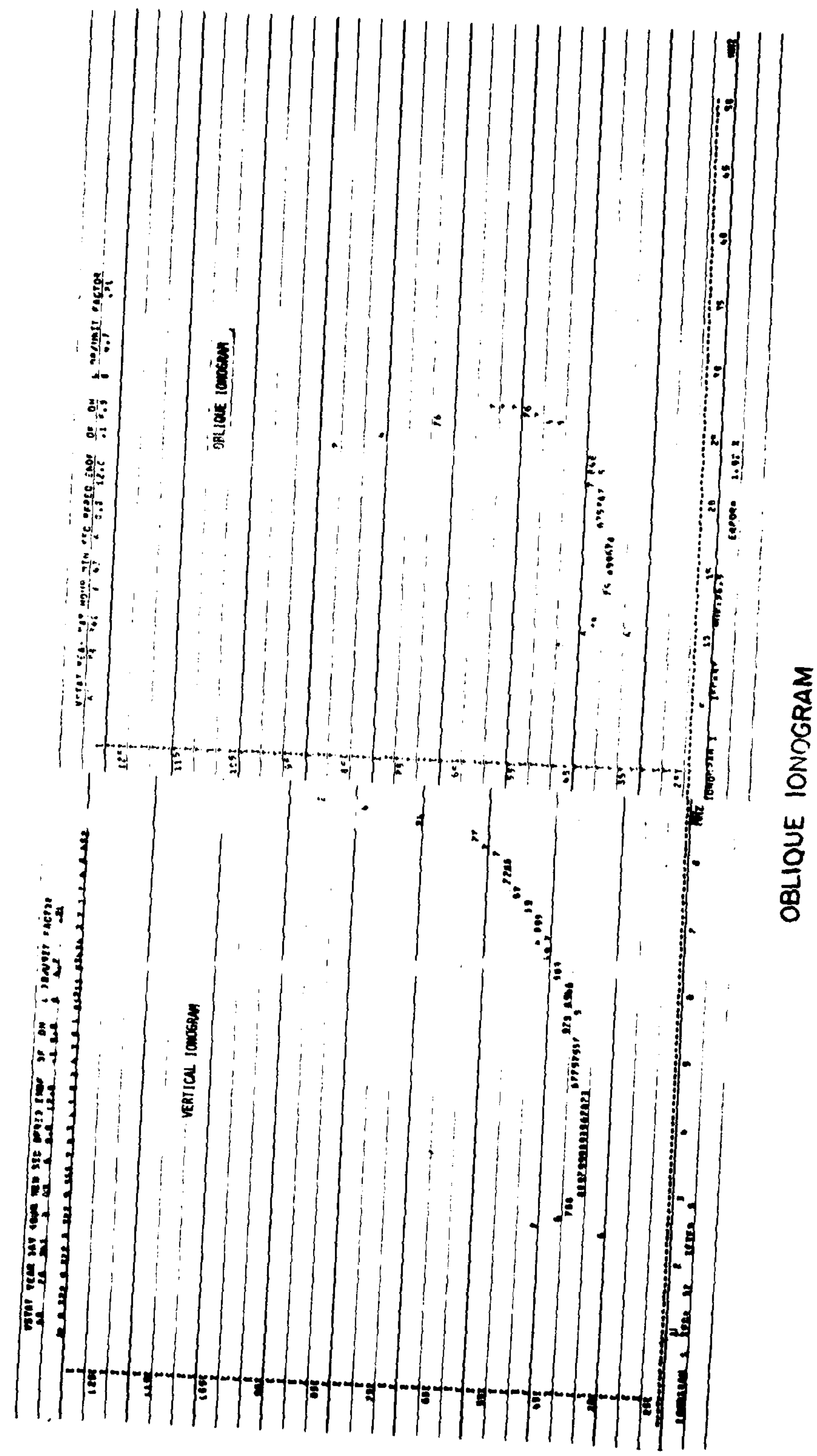


FIGURE 8

this method works well. In addition to the frequency of highest amplitude sum we also flag the highest oblique frequency. These two values usually vary by less than 2 or 3% but in the instance of an extraneous data point the variance is much greater. Therefore the summed amplitude method is preferred.

Since the MUF(3000) values are automatically extractable with high reliability we recommend to use them for global prediction and modelling. To provide M(3000) it is necessary to divide the MUF(3000) by foF2 which is available less accurately and also less frequently due to ionospheric reasons.

Determination of MUF(3000) by the described methods seems optimal for implementation in a microcomputer. The calculation itself requires only one look-up and one multiplication for each operating frequency.

2.1.2 fmin Determination

The three-point smoothing method is applied to both the E and F trace to determine fminE and fminF. The minimum of fminE and fminF is then selected as fmin. During the daytime the search for fminF begins at height 210 km and at the frequency f = foE. The median values of foE are tabulated for each month. When the height over four adjacent frequencies is consistent the initial frequency is cited as fmin. Due to the smoothing method up to two of the four frequencies could have zero data. ITFST, i.e. the change in echo range from one frequency to the next, is set to 18 km in the E-region and to 33 km in the F-region.

In the case where no beginning of the trace can be found, fmin, as well as the other three parameters of this ionogram are recorded with the letter B.

2.1.3 ftEs Determination

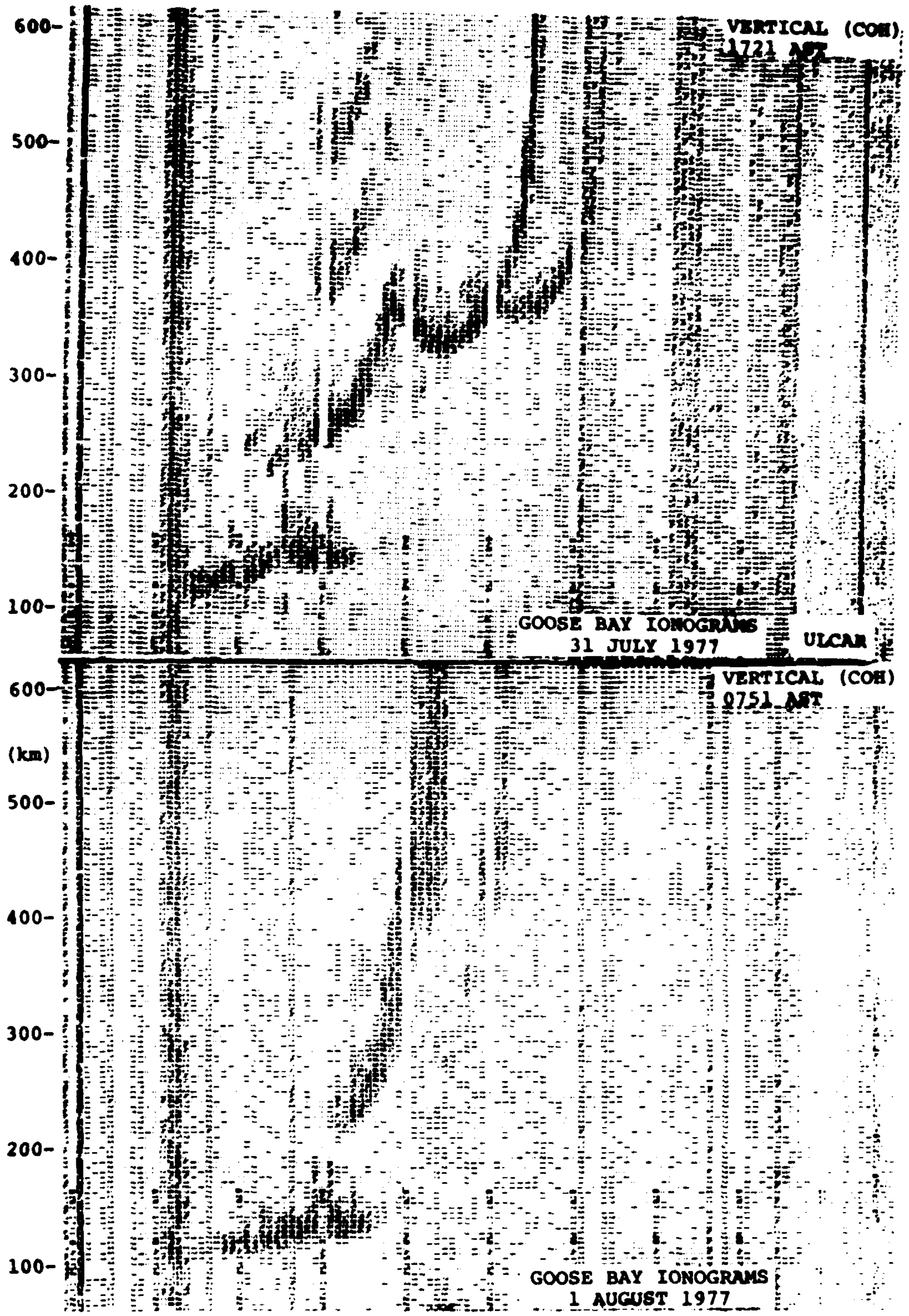
The value of ftEs is the last frequency of the consistent E-region trace. In arctic regions the manually scaled ftEs values may tend to be higher due to visual extrapolation. Frequency dependent fading and temporal variations of the received signals may produce Es layer traces breaking for 1-2 MHz and resuming at a higher frequency. The computer program implements the strict definition when scaling the ftEs. When four adjacent frequencies have zero data ftEs is assumed. If the criteria for the end of trace were increased to 0.5 MHz or greater the chance of noise being within an acceptable height window is too great and would result in errors.

To resolve this problem a search for a second Es trace beyond ftEs could deliver another ftEs which would be qualified. Since very often meteor echoes or short-lived aurora reflection cause this behavior, it is perhaps best to keep to the URSI definition and disregard this auroral Es phenomenon.

If ftEs lies within ±0.2 MHz of the tabulated foE value the slope of the E layer trace is investigated. If the data from ftEs - 0.6 MHz to ftEs has a predominately positive slope it is assumed there is no Es. For Goose Bay E region data this creates a problem. Very rarely is the E region well defined; the layer is consistently diffuse. In the case where the layer is diffuse we classify it according to convention as both E and Es. Spread E layers are seen in Figure 9. For mid-latitude stations the algorithm should work; and in Goose Bay the computer results should also be consistent with the scaling conventions.

2.2 Diurnal Variations

For daytime ionograms the A.P.E. program recognizes the main echo and determines foF2 and MUF to within a small



600-
500-
400-
300-
200-
100-
VERTICAL (COH)
1721 AST
GOOSE BAY IONOGRAMS
31 JULY 1977
ULCAR
600-
VERTICAL (COH)
0751 AST
(km)
500-
400-
300-
200-
100-
GOOSE BAY IONOGRAMS
1 AUGUST 1977

FIGURE 9

error. Most errors during the day are caused by high noise interference, strong absorption or attenuation in the vicinity of the critical frequency. For night ionograms in the auroral region spread F, low critical frequencies, and presence of oblique traces create trace recognition problems. For a mid-latitude station these errors would be less significant.

Some time-of-day tests have been built into the system. Time of day qualifications on the ionogram use sunrise and sunset (plus two hours) to distinguish cut-off for day and night. Specifically, the minimum acceptable foF2 (MINFRQ) is 2.0 MHz during night and 4.0 MHz during day. Since the radio band extends to approximately 1.5 MHz the 2.0 MHz limit permits a trace of 0.5 MHz length to constitute a layer at night. The minimum height of the F layer is apt to be greater than 300 km during the night. For the night ionograms the search for fminF does not start at 210 km altitude (see Section 2.1.2) but at the average height of the first three contiguous F-region echoes.

2.3 Qualifying Numerical Output

Although it is the paramount purpose of the program to extract the best "refined" ionogram possible which would permit accurate determination of the URSI parameters, it is also important to qualify any parameters which have inherent errors. The URSI qualifying and descriptive letters referred to in this chapter are described briefly in Appendix B and more precisely in the "URSI Handbook of Ionogram Evaluation and Reduction" (Piggott and Rawer, 1972).

The letter F is used to qualify the A.P.E. foF2 and MUF(3000) if the primary F layer spread indicator DF is sufficiently large. For a perfect reflector we would expect the echo spread to be equal to the Digisonde pulse width W (i.e.

100 μsec or 15 km). Anything greater than 15 km would indicate spread. A continuous spread of greater than 40 km over 1.0 MHz near the critical frequency would qualify the foF2 reading with an F. This is comparable to UF when the data is manually scaled. On an undisturbed ionogram the apparent spread should only be significant from foF2 minus 0.3 MHz to the critical frequency when the slope of the trace becomes very large as a result of the finite spectral width of the transmitted rf pulse. If the spread is continuous for over 1.5 MHz FF is outputted and the numerical value ignored.

The Geomonitor's algorithm for matching the received pulse shape with a characteristic filter has limitations whenever spread conditions prevail. Therefore the minimum height of the F trace may be slightly inconsistent. An attempt will be made to use the DF parameter to define the inside edge of the echo trace for an improved foF2 determination. A study was made on the direction of the error when spread occurs. On most occasions the A.P.E. program defines foF2 between 0.2 - 0.6 MHz higher than a manually scaled ionogram which takes the inside (lowest frequency) edge of the spread.

The numerical values for foF2 and MUF are qualified with the letter R if the maximum virtual height is less than 350 km.

If the foF2 defined by A.P.E. is within 0.2 MHz of the end-frequency of the ionogram, the numerical value is qualified with DD, indicating that the value may be higher.

If no F or Es trace exists, i.e. no ten frequencies (0.1 MHz increments) with contiguous data were found, then a B replaces the values for fmin, foEs, foF2, MUF(3000). In the case where an Es trace but no continuous F trace exists, A replaces the numerical F-region values.

3.0 COMPARISON BETWEEN MANUALLY AND AUTOMATICALLY SCALED PARAMETERS

To evaluate the performance of the A.P.E. program we compared the parameter values determined by A.P.E. with those obtained by manually scaling the ionograms. Since foF2 is the most difficult parameter to determine accurately, especially under disturbed ionospheric conditions, the correlation analysis concentrated on this parameter. More than 1200 ionograms from Goose Bay were included in the analysis. Two data groups were analyzed separately: 1) 40 ionograms that were recorded with the Digisonde 128, and hence included the extraordinary trace and 2) 1242 ionograms recorded with the Digisonde 128PS.

3.1 Data Group I

These 40 ionograms cover a period from 2137 AST on 2 July 1978 to 0730 AST on 3 July 1978. We define the foF2 error as the difference between the manually and the A.P.E. evaluated parameter

E(foF2) = Manual foF2 - A.P.E. foF2.

It should be noted that this error includes the system error of the Geomonitor. When discussing Data Group II we will separate the error introduced by the Geomonitor and the A.P.E. program. Figure 10 shows the error distribution function for foF2. For 86% of the data the error lies within ±0.2 MHz, and for 89% it lies within ±0.5 MHz. The individual errors for all 40 ionograms become visible by comparing the foF2 curves obtained by manual and A.P.E. scaling (Figure 11). The main deviations occur at ionograms No. 4, 7, 11, 15 and 22. Ionogram No. 4 had large spread F and the Geomonitor found significant jumps in echo heights for adjacent frequen-

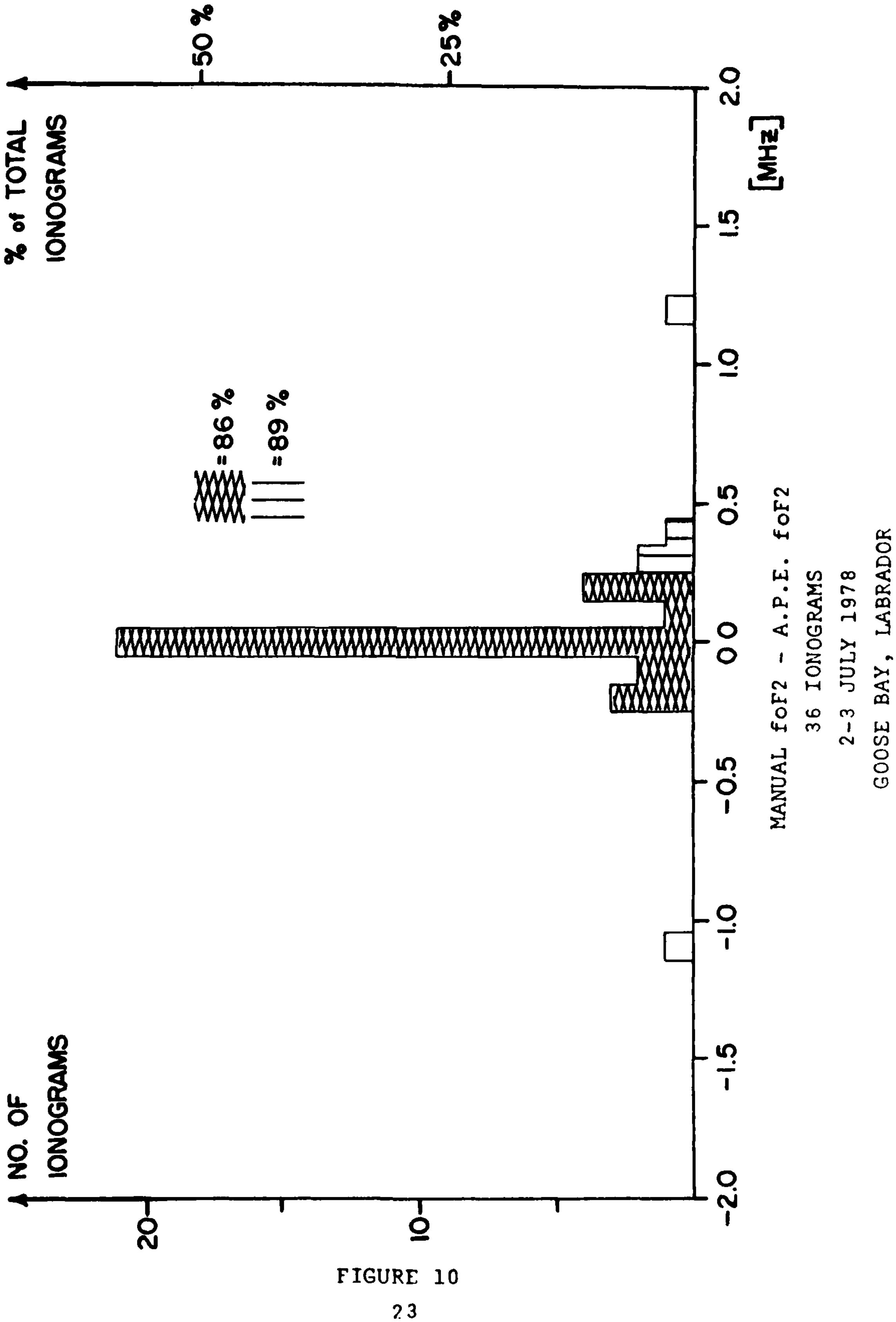
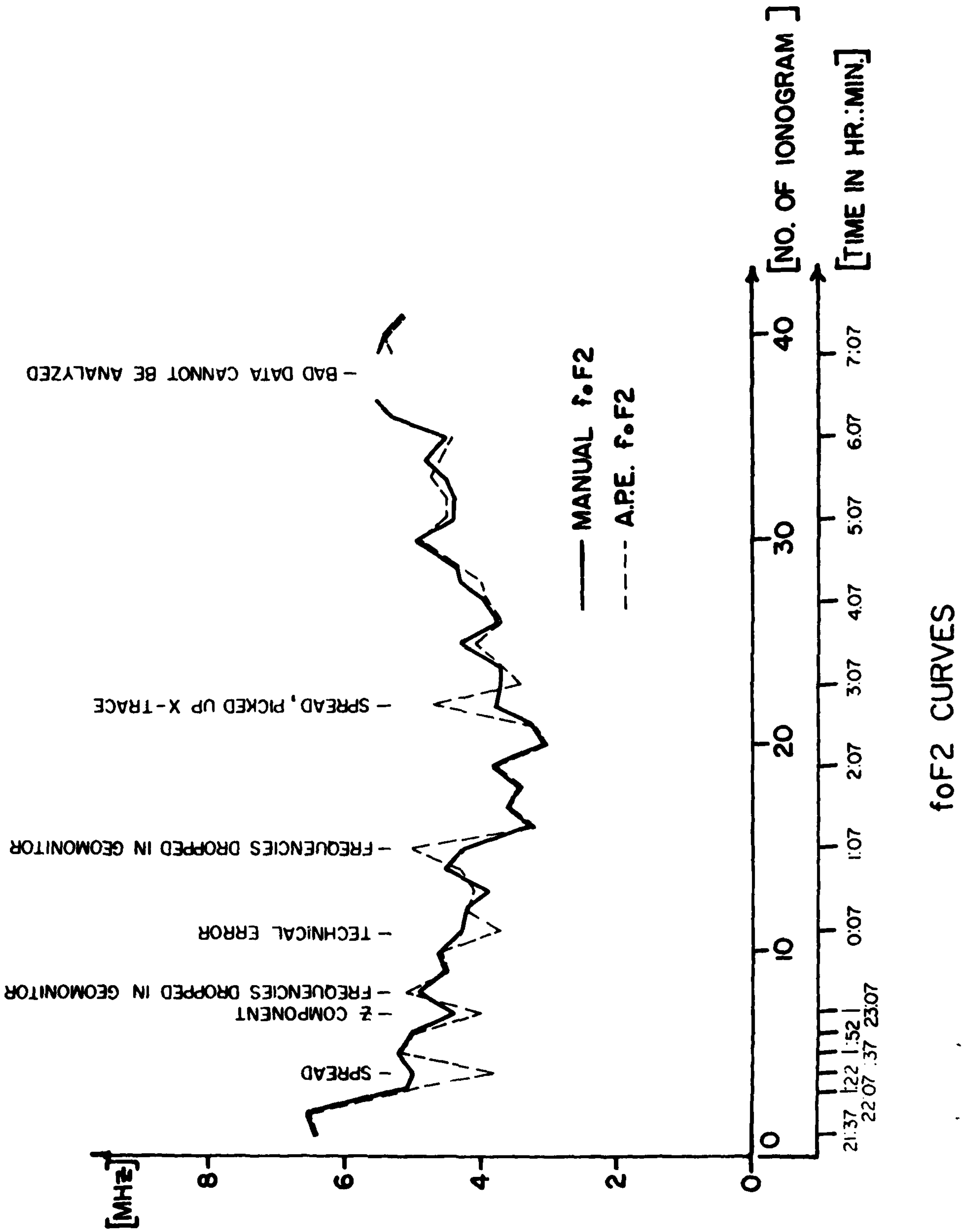

% of TOTAL IONOGRAMS
50 %
25 %
NO. OF IONOGRAMS
20
10
=86 %
=89 %
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
[MHz]
MANUAL foF2 - A.P.E. foF2
36 IONOGRAMS
2-3 JULY 1978
GOOSE BAY, LABRADOR

FIGURE 10



foF2 CURVES
MANUAL f₀F2
A.P.E. f₀F2
[MHz]
[NO. OF IONOGRAM]
[TIME IN HR.:MIN.]
SPREAD
Z COMPONENT
FREQUENCIES DROPPED IN GEOMONITOR
TECHNICAL ERROR
FREQUENCIES DROPPED IN GEOMONITOR
SPREAD, PICKED UP X-TRACE
BAD DATA CANNOT BE ANALYZED

FIGURE 11

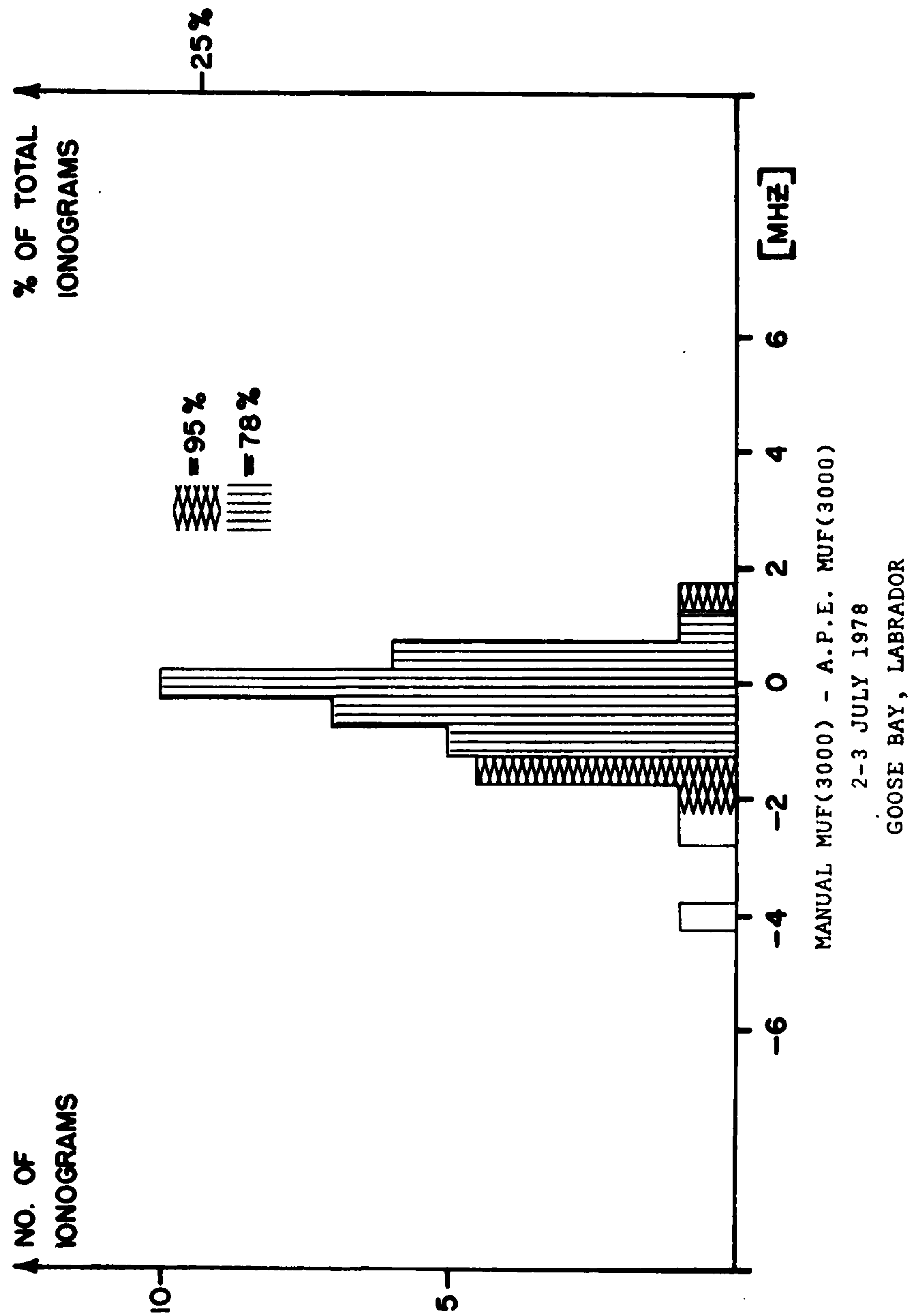
cies. The A.P.E. program in consequence misinterpreted the data. Ionogram No. 7 showed a strong Z trace which A.P.E. mistook as O trace, since no safeguards against the Z trace are built into the program. In Ionogram No. 22 A.P.E. selected fxF2 since strong F spread was distorting the Geomonitor data. The errors at points 11 and 15 are caused by technical errors and hence were not included in the distribution function of Figure 10. A magnetic tape bit error caused the deviation in ionogram 11. For ionogram 15 the Geomonitor had dropped eight frequencies between 2 and 4 MHz and the A.P.E. program consequently assigned wrong frequencies to the data points. Figure 12 shows the corresponding error distribution function for the MUF(3000). Of the 37 ionograms 29, or 78% are scaled accurately within ±1 MHz, and 95% within ±2 MHz. This is an excellent result and verifies the right selection of the MUF algorithm.

3.2 Data Group II

When the data from the Digisonde 128PS became available the program was further refined using the new data which has the extraordinary echoes suppressed. The data itself is superior to the 128 data because of the improved preprocessing features of the Digisonde 128PS.

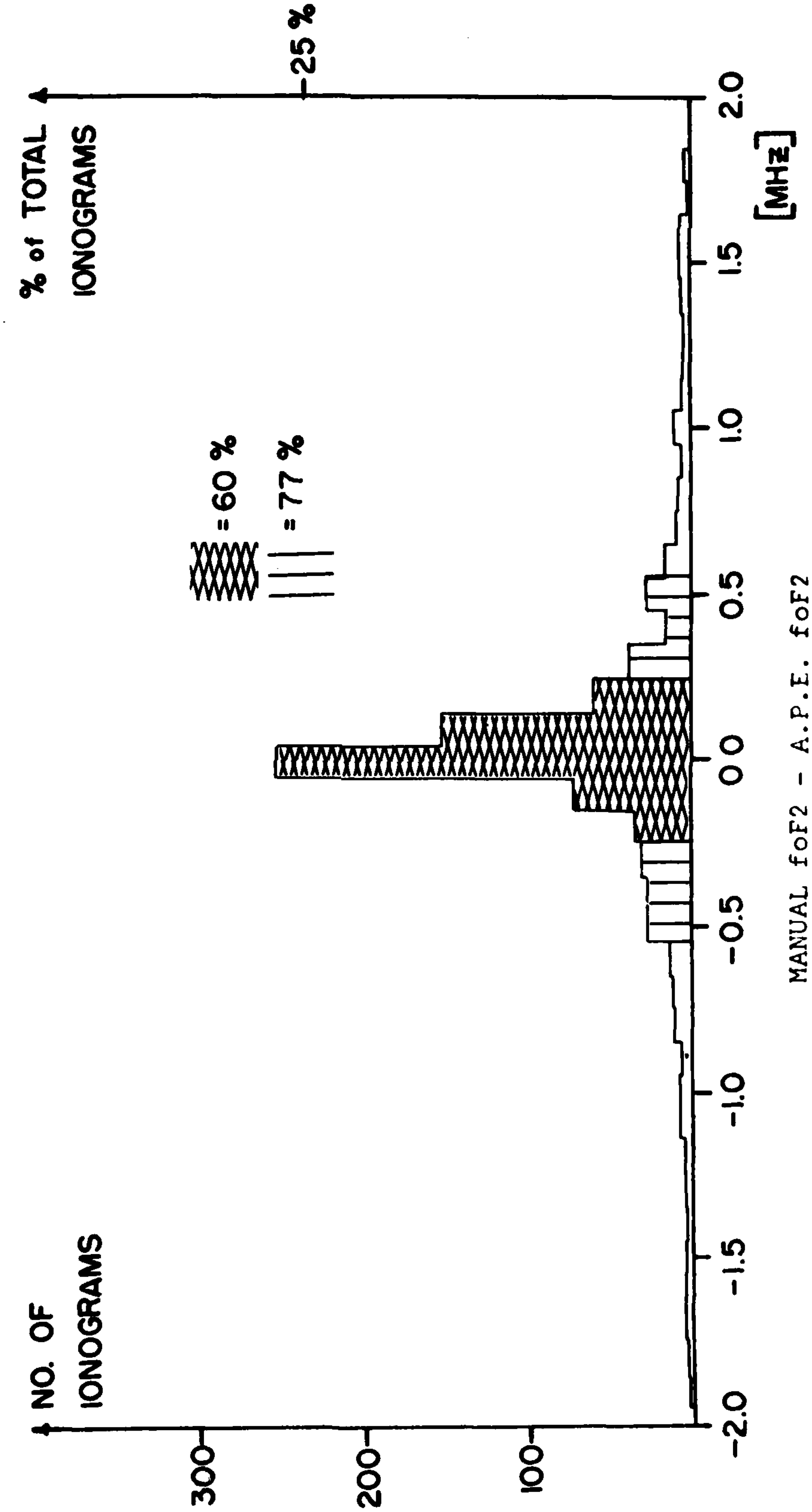
A nine day period from 5 to 13 January 1979 was evaluated in the A.P.E. program. We were able to recognize certain prevalent disturbed conditions. After conducting some special tests we found that errors occurred largely when there was extensive spread F or absorption in the vicinity of foF2. Under these conditions even the manual scaling becomes a subjective task.

1242 ionograms were analyzed to produce the information in Figures 13 - 18. Figures 13 and 14 display the foF2 as evaluated by A.P.E. and its deviation from the manually



NO. OF
IONOGRAMS
% OF TOTAL
IONOGRAMS
25%
10
5
= 95%
= 78%
-6
-4
-2
0
2
4
6
[MHZ]
MANUAL MUF(3000) - A.P.E. MUF(3000)
2-3 JULY 1978
GOOSE BAY, LABRADOR

FIGURE 12



MANUAL foF2 - A.P.E. foF2
948 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 13

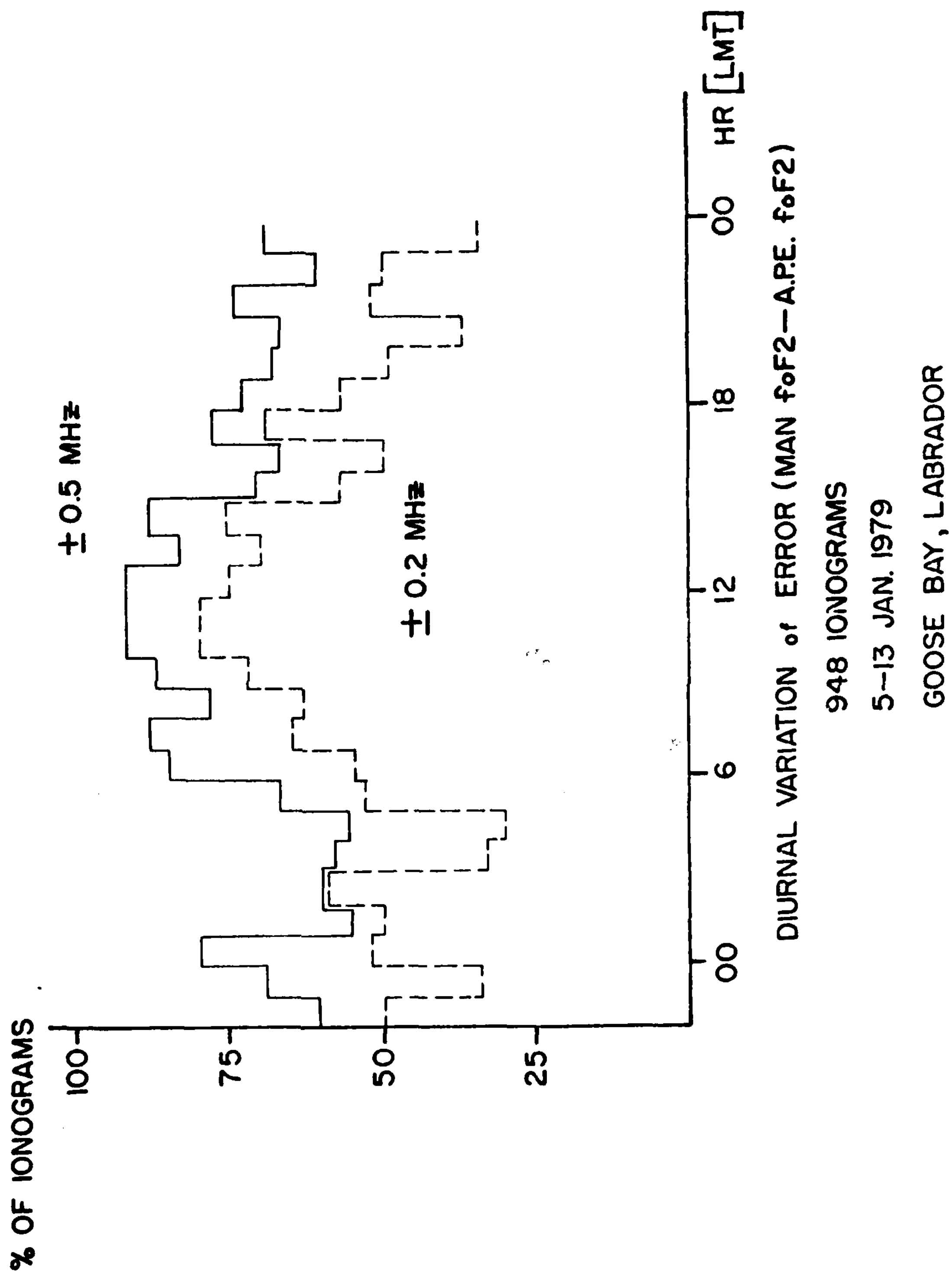
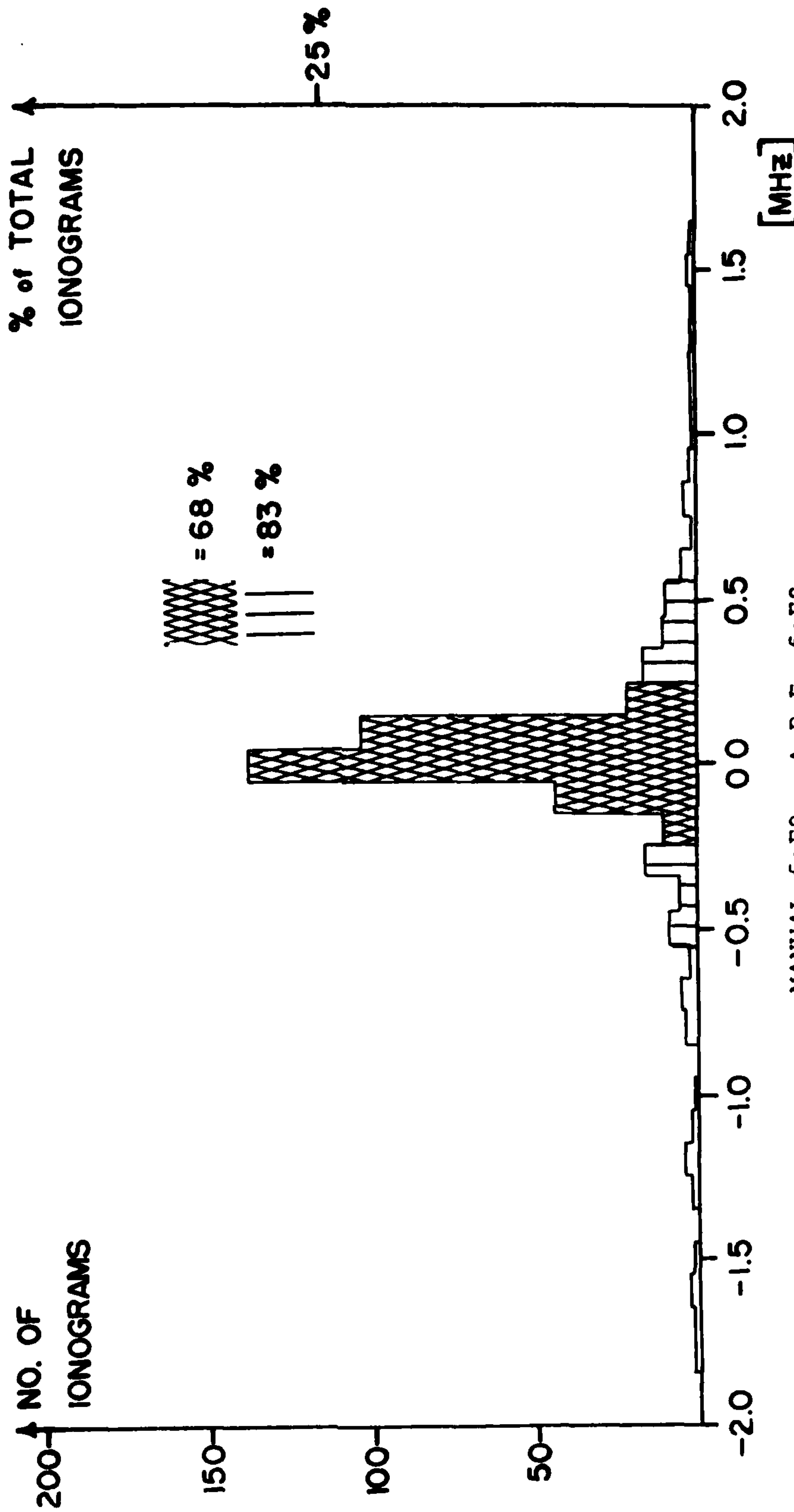
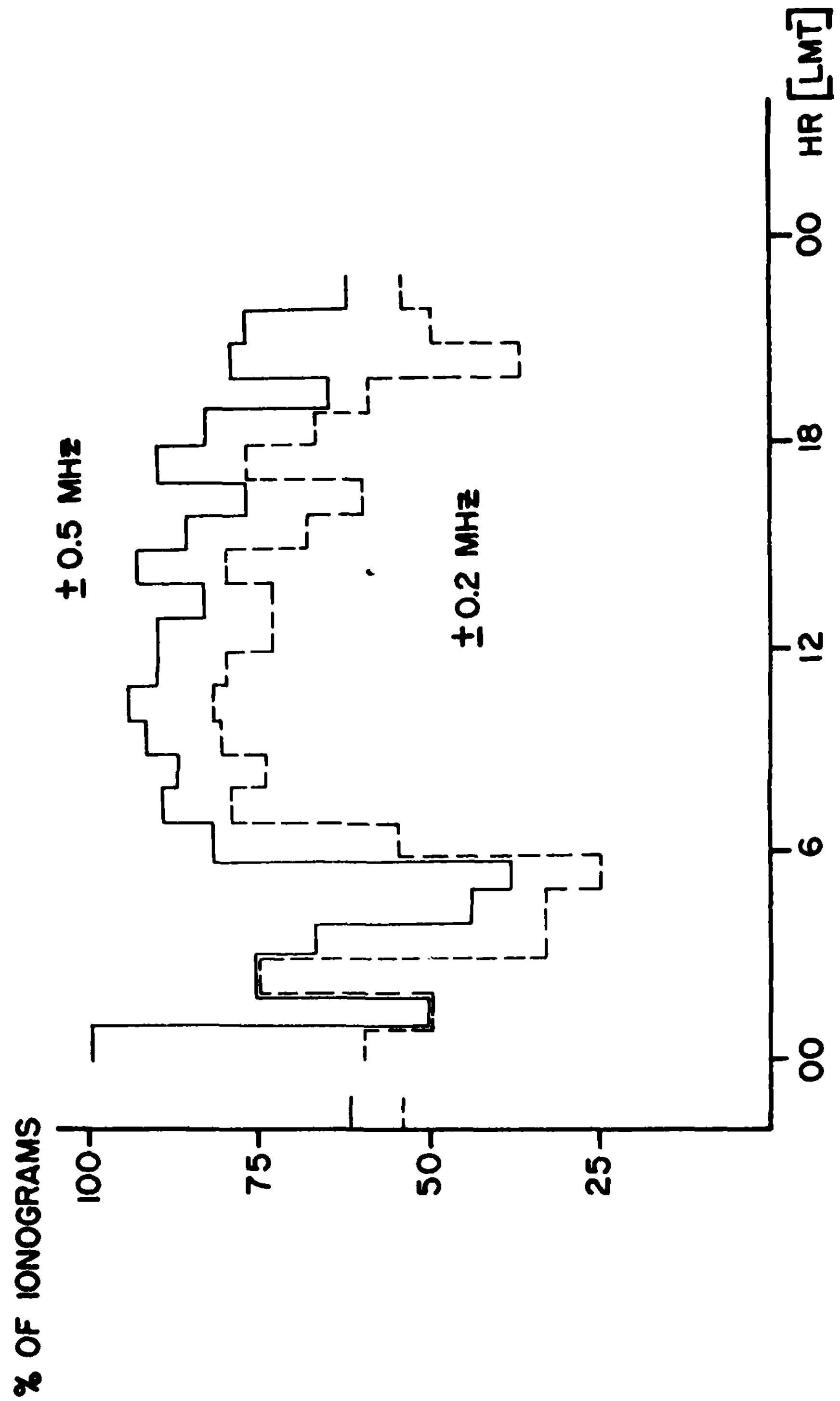

% OF IONOGRAMS
100
75
50
25
00
6
12
18
00
HR [LMT]
± 0.5 MHz
± 0.2 MHz
DIURNAL VARIATION of ERROR (MAN foF2—A.P.E. foF2)
948 IONOGRAMS
5–13 JAN. 1979
GOOSE BAY, LABRADOR

FIGURE 14



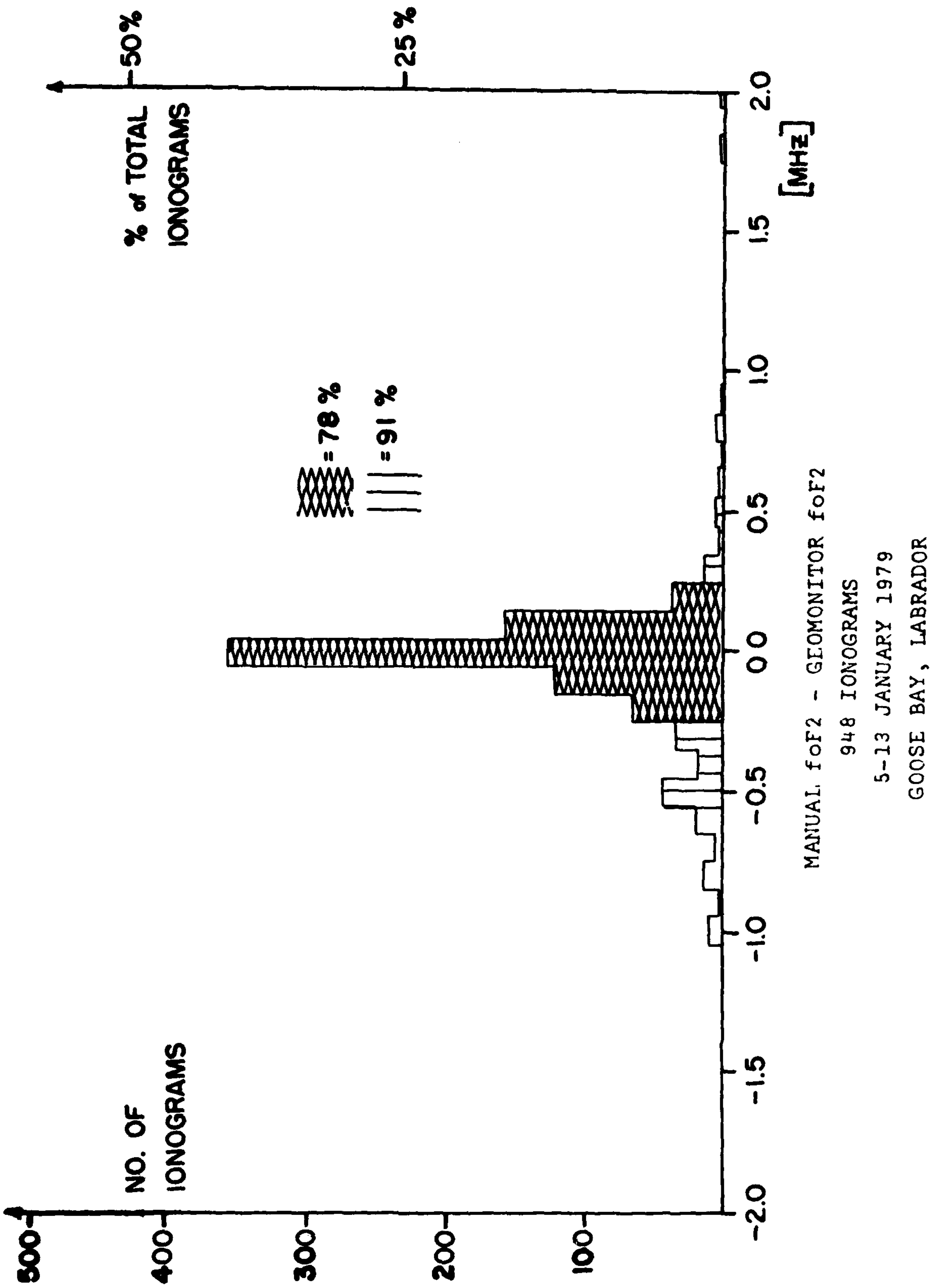
MANUAL foF2 - A.P.E. foF2
467 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 15



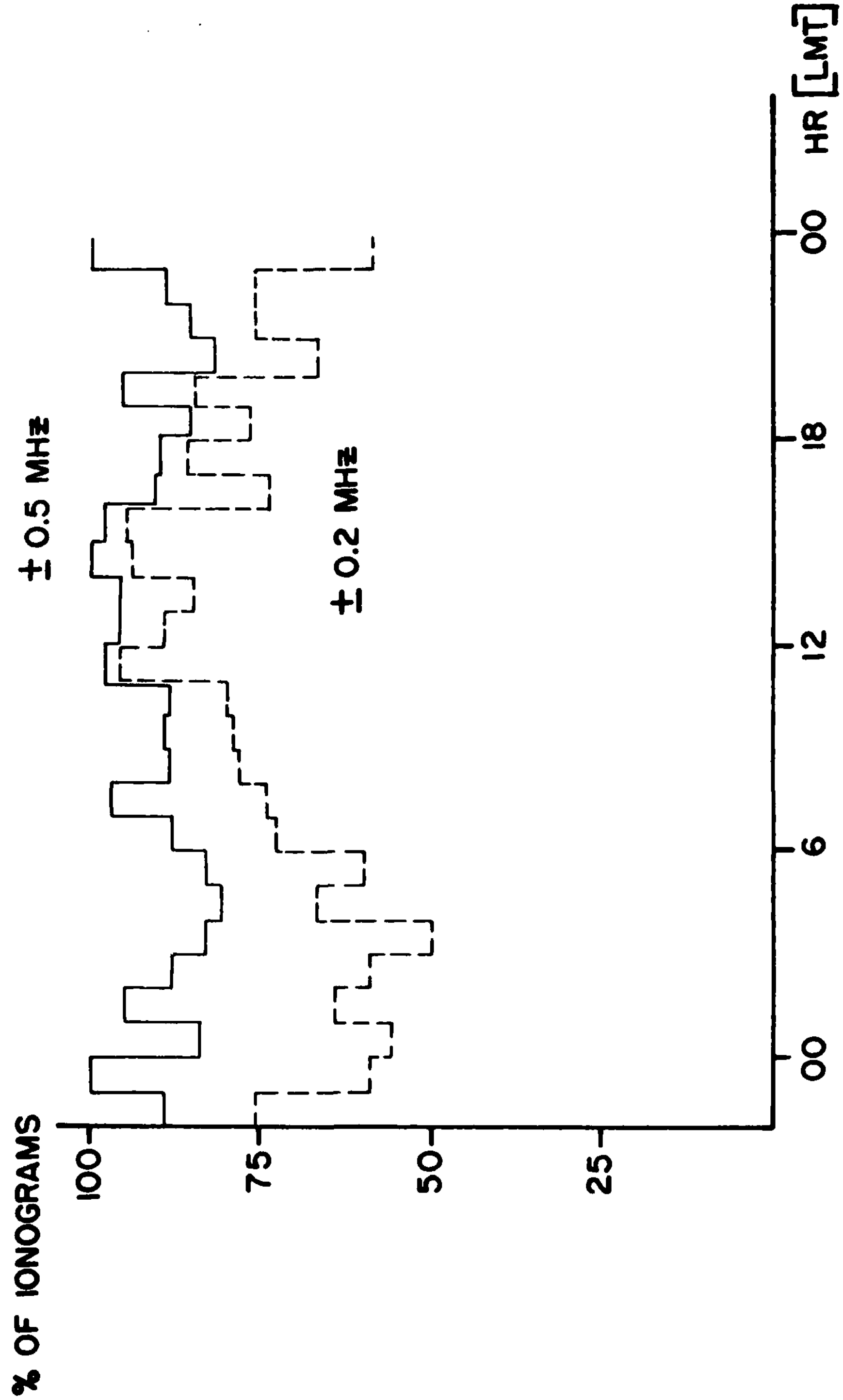
DIURNAL VARIATION OF ERROR (MANUAL foF2 - A.P.E. foF2)
467 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 16



% of TOTAL
IONOGRAMS
50%
25%
[MHz]
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
=78%
=91%
MANUAL foF2 - GEOMONITOR foF2
948 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR
NO. OF
IONOGRAMS
500
400
300
200
100

FIGURE 17



DIURNAL VARIATION OF ERROR (MANUAL foF2 - GEOMONITOR foF2)
948 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 18

scaled parameters. For 77% of all ionograms foF2 was determined within half a MHz. The best results are obtained around noon (90%) and the worst at early morning and evening (Figure 14). Table 1 lists the number of ionograms at different hours of the day for the diurnal variation of error plots. When manually scaling the 1242 ionograms, 481 had qualified values of foF2, and in 294 cases the reading was impossible. A coding error in the Geomonitor's firmware resulted in a noise threshold that became very high in case of spread conditions causing the F-trace to become very bumpy. For 204 ionograms this technical error made it impossible to intelligently scale the foF2 values from the reconstituted Geomonitor ionograms. Erroneous frequency identification on the Geomonitor tapes caused errors of up to 0.8 MHz. These technical errors explain 204 cases. The remaining 90 cases are explained by strong absorption or night E. For 68% of the ionograms, the A.P.E. evaluated the very spread layers for a reasonable ftF. Figures 15 and 16 display the foF2 error: manual foF2 - A.P.E. foF2 and the hourly distribution of error for the 467 non-qualified ionograms which is only 37% of the used sample of Goose Bay data. Here 83% of the foF2 values are accurate within one-half MHz and 68% within 0.2 MHz.

In cases when a slight spread occurs we would expect the value of A.P.E. foF2 to be slightly larger than the manually scaled foF2. After 21 January 1979 the hourly sequence of ionograms provided X-trace suppression on all six ionograms. Prior to this date one of every six ionograms, the one starting at 59 minutes past the hour, had both O and X-traces. This explains the secondary maximum at -0.5 MHz on both Figures 13 and 15. The gyrofrequency fH at Goose Bay is 1.4 MHz, i.e. the separation between fxF2 and foF2 is 0.7 MHz.

It is reasonable to assume that the error peak at -0.5 MHz is caused by the X-trace. This assumption was verified by checking the individual ionograms. In some cases,

Figure No.	HOUR [AST]																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
14, 18	29	25	22	17	12	27	30	33	34	49	53	51	50	53	53	49	42	46	51	44	47	51	42	38
16, 20	3	5	4	4	3	9	8	11	19	31	36	33	40	30	30	30	22	30	30	18	17	19	22	13
22	29	31	33	24	22	33	35	34	35	49	54	51	51	52	52	51	45	49	52	44	49	50	43	38
24	3	5	4	4	3	9	7	11	19	31	36	33	40	29	30	30	22	30	30	18	17	19	22	13
26	29	25	22	17	12	27	30	33	34	49	53	50	50	52	53	49	36	45	51	44	46	51	42	38
28	3	5	4	4	3	9	8	11	19	31	36	33	40	29	30	30	22	29	30	18	17	19	22	13

NUMBER OF PROCESSED IONOGRAMS AT DIFFERENT HOURS OF THE DAY

JANUARY 5-13, 1979

GOOSE BAY, LABRADOR

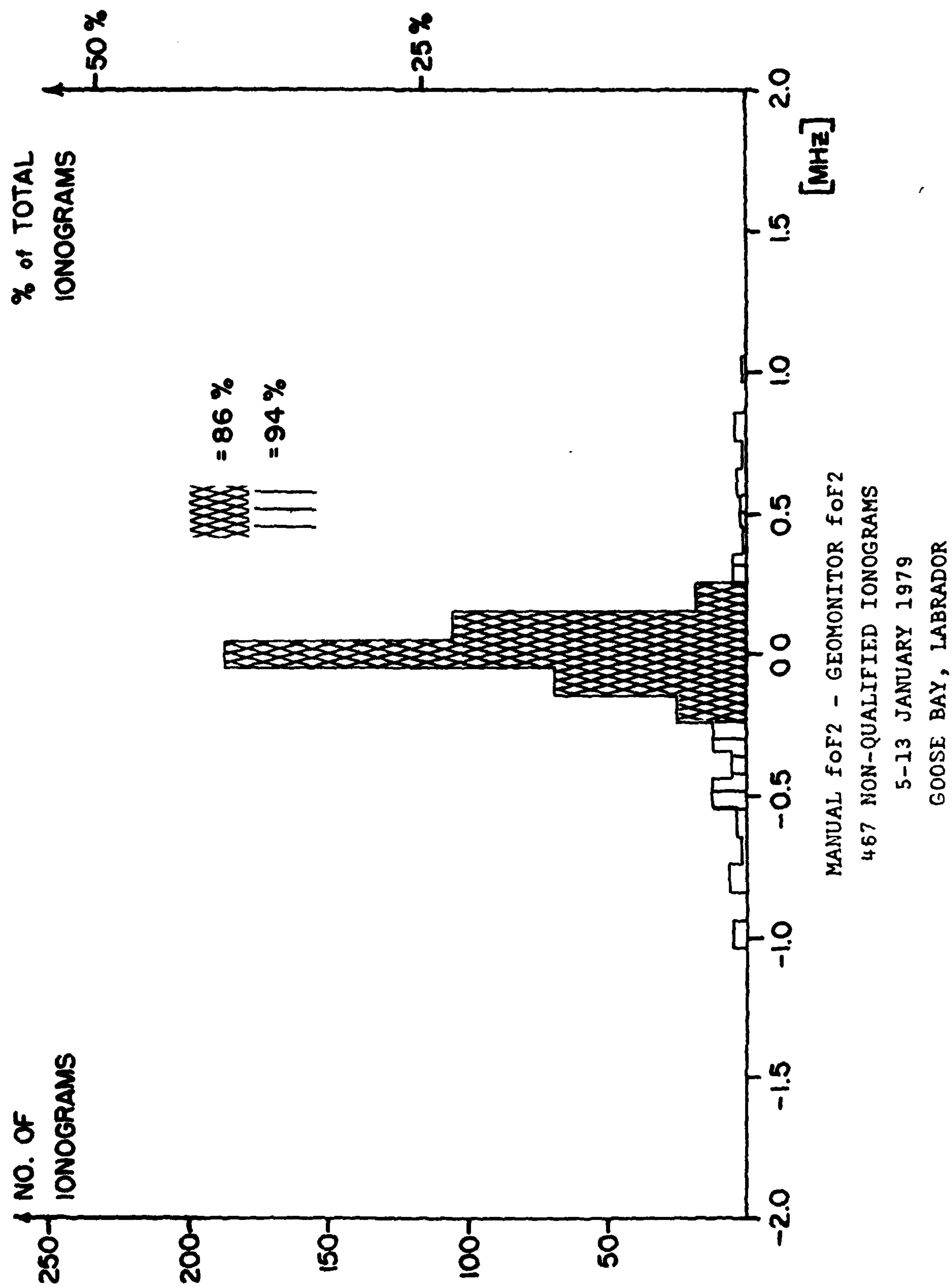
TABLE 1

the existence of the Z-component or an oblique layer leads the A.P.E. to misinterpret foF2 (Figure 29). The error peak at +0.5 MHz accounts for this phenomenon. Not shown in Figure 13, but included in the diurnal curves, are 72 ionograms, approximately 8% of the total, whose absolute error is greater than 2.0 MHz. For the data of Figure 15, 6% of all ionograms had errors greater than 2.0 MHz which are not shown in the plot.

The only data from Goose Bay which resemble undisturbed conditions are the daytime ionograms. Figures 14 and 16 display the ±0.5 MHz and the ±0.2 MHz errors as a function of time of day. Figure 16 shows that the number of daytime (noon ± 2 hr) cases with absolute errors of 0.5 MHz or less is 92%, and for absolute errors of 0.2 MHz or less is 75%. At Goose Bay the evaluation of foF2 becomes more difficult with the onset of particle precipitation producing thick E layers, absorption and intense spread.

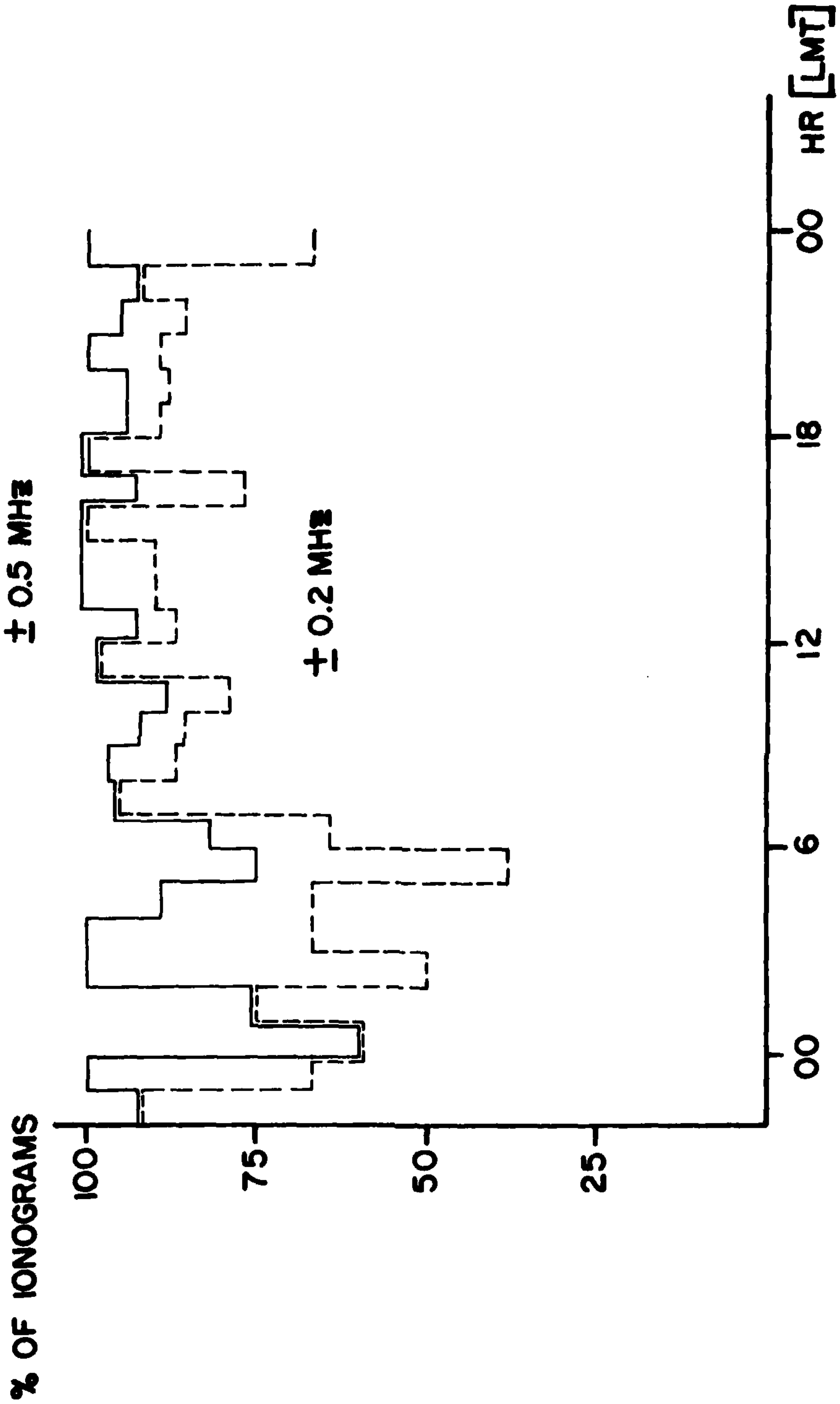
The errors presented in Figures 13-16 are the joint errors of the Geomonitor microcomputer and the A.P.E. program. For the period from 5-13 January, 1242 ionograms were reconstituted from the taped Geomonitor data to produce outputs such as Figure 2a and these ionograms were manually evaluated for foF2. This way we are able to define the error caused by the Geomonitor. Figure 17 and Figure 18 show the error and diurnal variation of the error defined as the difference between the manually scaled foF2 values obtained from the full ionogram and the reconstituted Geomonitor ionogram.

Figures 19 and 20 show the error distribution function and diurnal variation for all non-qualified data during the nine day period. In Figure 19, 94% of the foF2 values are accurate within 0.5 MHz and 86% within 0.2 MHz. Figure 20 shows that even at nighttime, up to 100% of the cases with absolute errors of 0.5 MHz or less are obtained. It is because a great number of ionograms are qualified at those hours, only a few ionograms are left for analysis and one case difference will affect the percentage drastically.



% of TOTAL IONOGRAMS
50%
25%
NO. OF IONOGRAMS
250
200
150
100
50
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
[MHz]
=86%
=94%
MANUAL foF2 - GEOMONITOR foF2
467 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 19



DIURNAL VARIATION OF ERROR (MANUAL foF2 - GEOMONITOR foF2)

467 NON-QUALIFIED IONOGRAMS

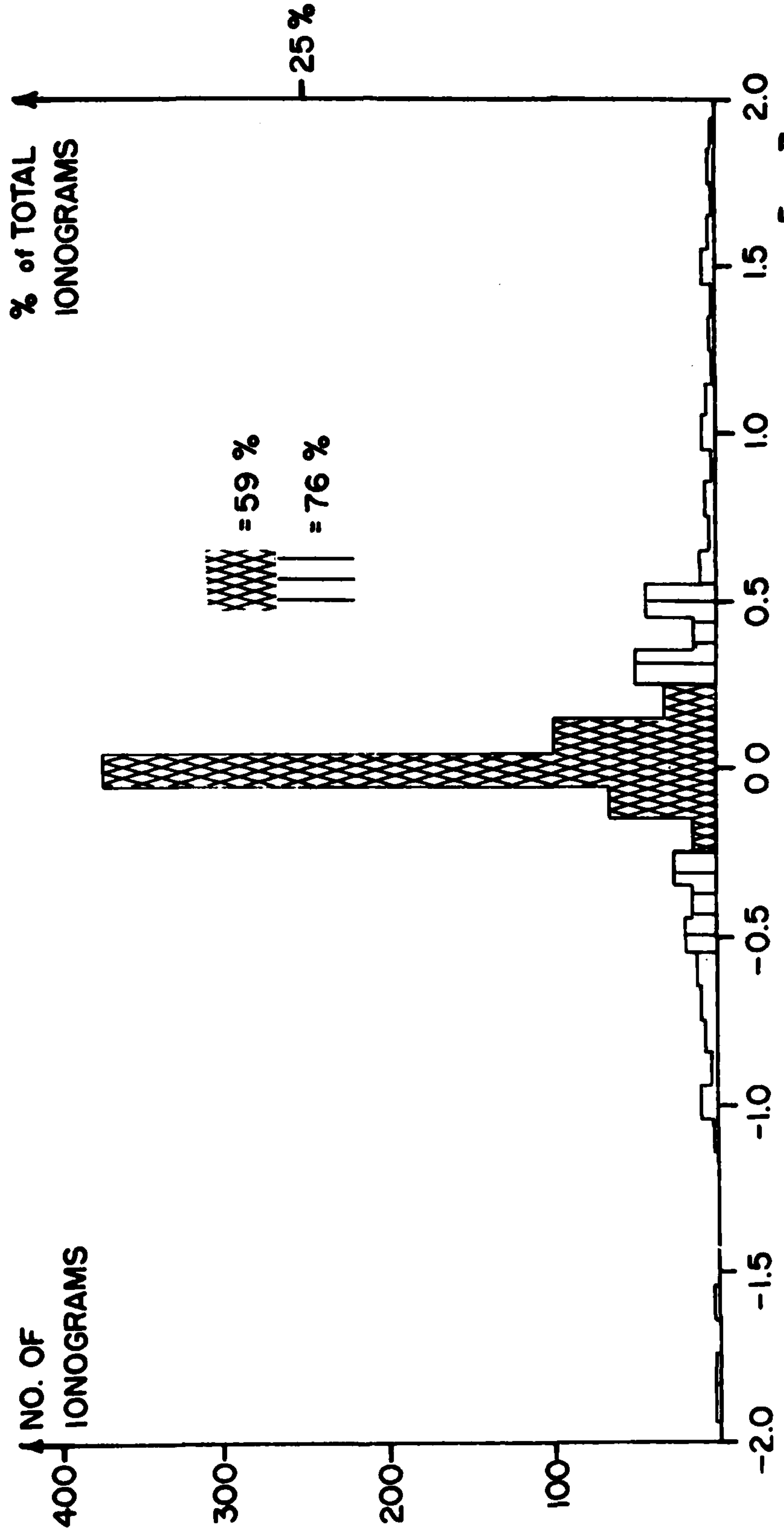
5-13 JANUARY 1979

GOOSE BAY, LABRADOR

FIGURE 20

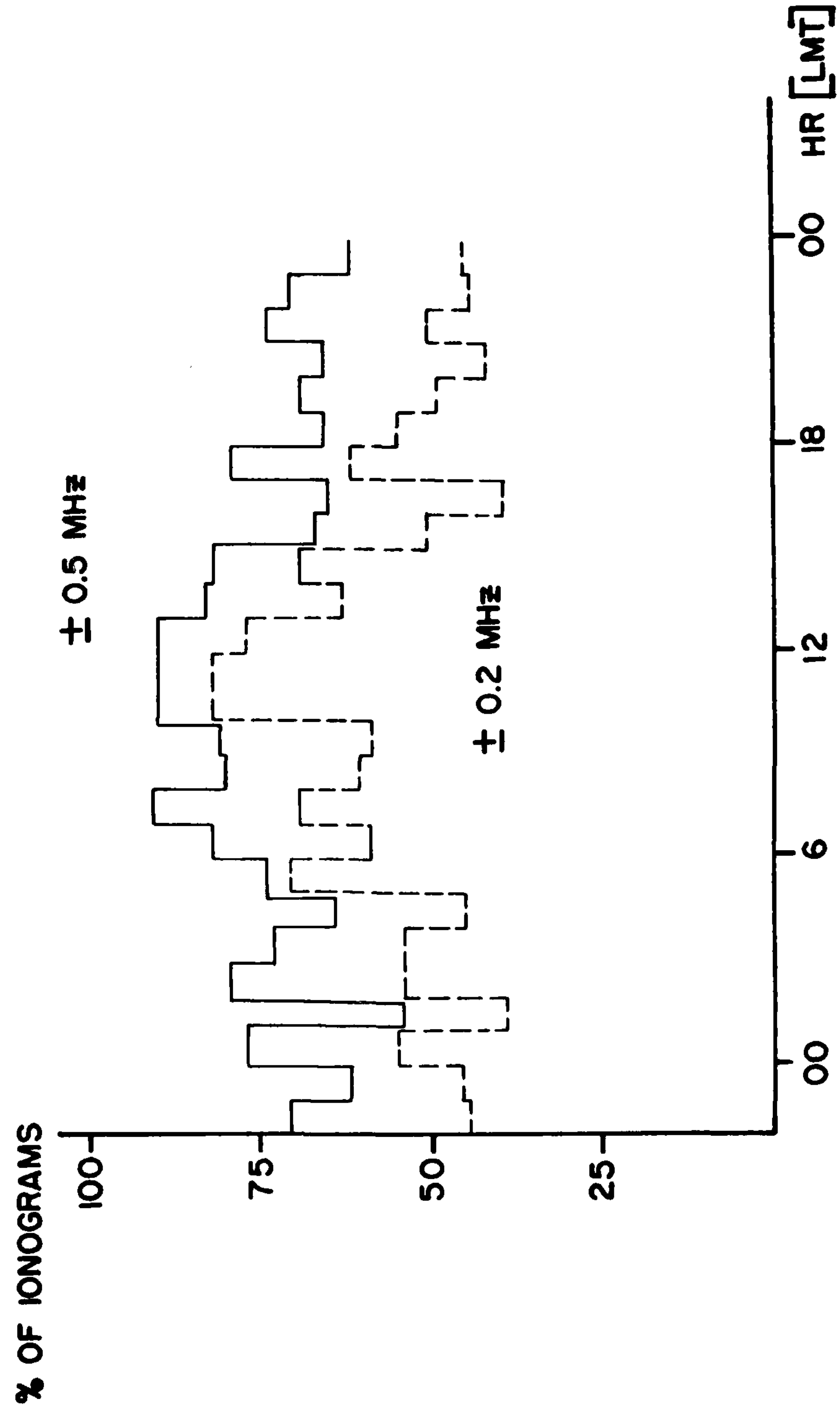
To separate the errors introduced by the Geomonitor and by the A.P.E. algorithms we compared the A.P.E. parameters with those that best human interpretation scaled from the reconstituted Geomonitor ionograms. The difference between the Geomonitor foF2 and the A.P.E. foF2 is a measure of the quality of the A.P.E. algorithms, since the data base, i.e. the Geomonitor data, is common for both visual and automatic scaling. Of a total of 1006 ionograms, the algorithm finds foF2 within ±.2 MHz for 59% of the cases, and within ±.5 MHz for 76% (Figure 21). For the 465 non-qualified ionograms accurate scaling (±0.2 MHz) is achieved in 65% of the cases, while 82% are scaled within ±0.5 MHz (Figure 23). Figures 22 and 24 show the diurnal variation of the A.P.E. error. Again, it is evident that the algorithm works less reliably for nighttime ionograms.

When manually scaling MUF(3000) the operator usually uses 0.5 MHz increments. The URSI overlays provide MUF curves in 1.0 MHz increments from 5.0-20 MHz; beyond 20 MHz the MUF curves are in 2.0 MHz increments. The automatic MUF scaling has a resolution of 0.5 MHz over the entire frequency range. Presently, the MUF calculation is performed on the trace after application of the A.P.E. trace identification algorithm, and the error in determining foF2 is carried to the MUF. We are in the process of changing this sequence. Conventions for taking the MUF when there is a spread condition have caused some discrepancies compared to the manually scaled values. The same tests which qualify the foF2 also carry the qualification to the MUF. Some additional effort may be needed to diminish the error in cases of spread F. Figures 25 and 26 show the error of MUF and the hourly distribution of the errors for all ionograms. Figures 27 and 28 show the results for the non-qualified ionograms. The larger errors are caused by spread F and oblique echoes.



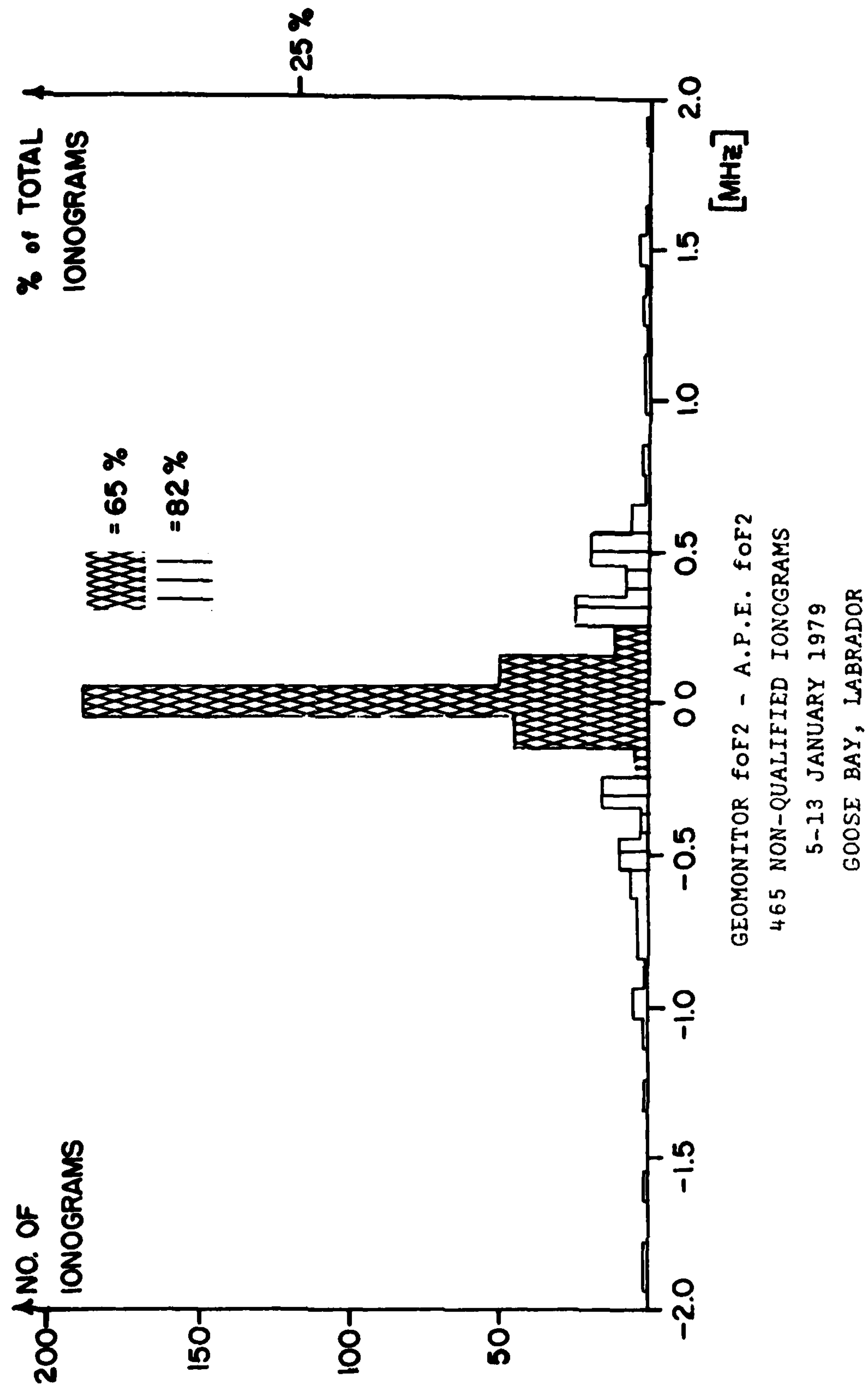
GEOMONITOR foF2 - A.P.E. foF2
1006 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 21



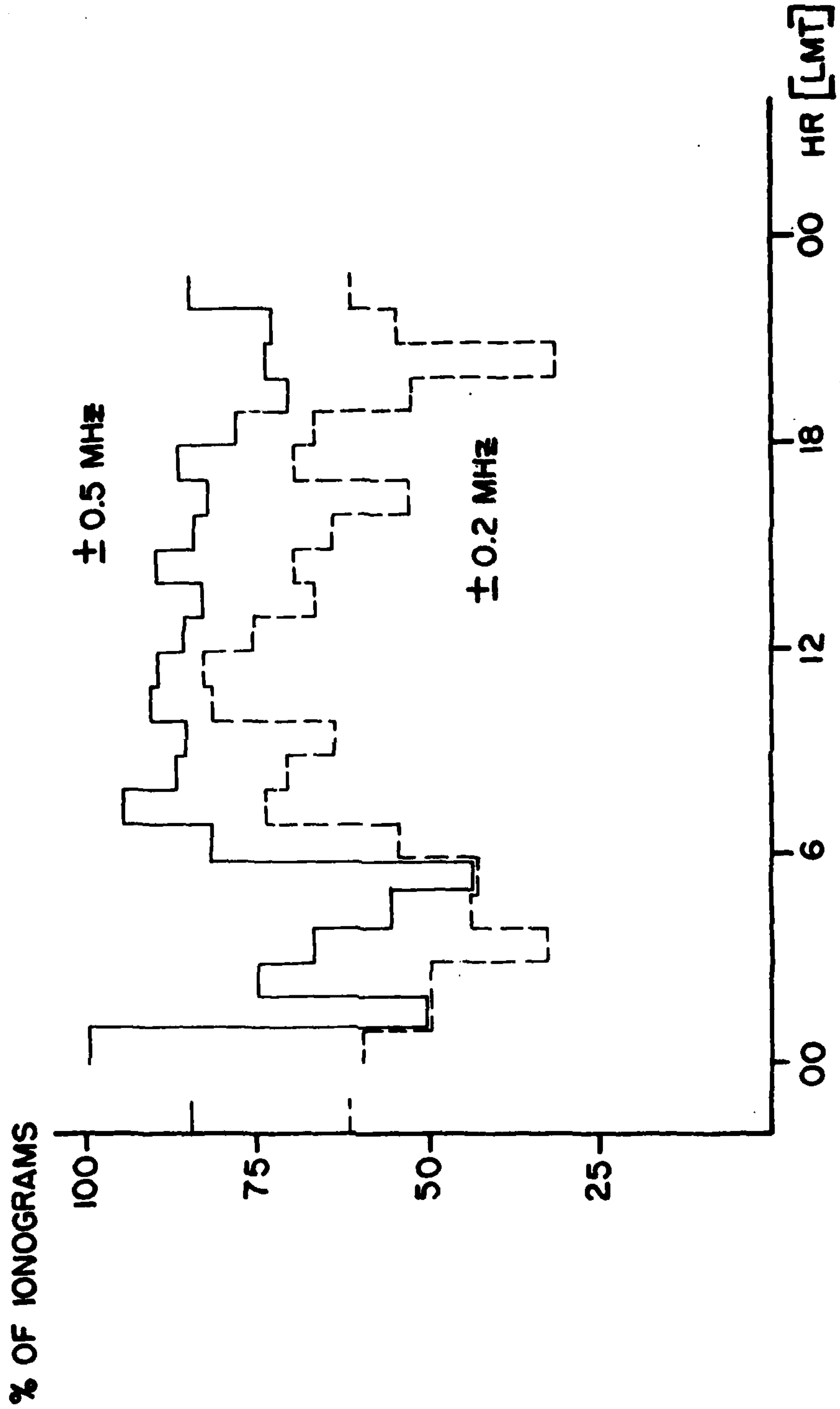
DIURNAL VARIATION OF ERROR (GEOMONITOR foF2 - A.P.E. foF2)
1006 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 22



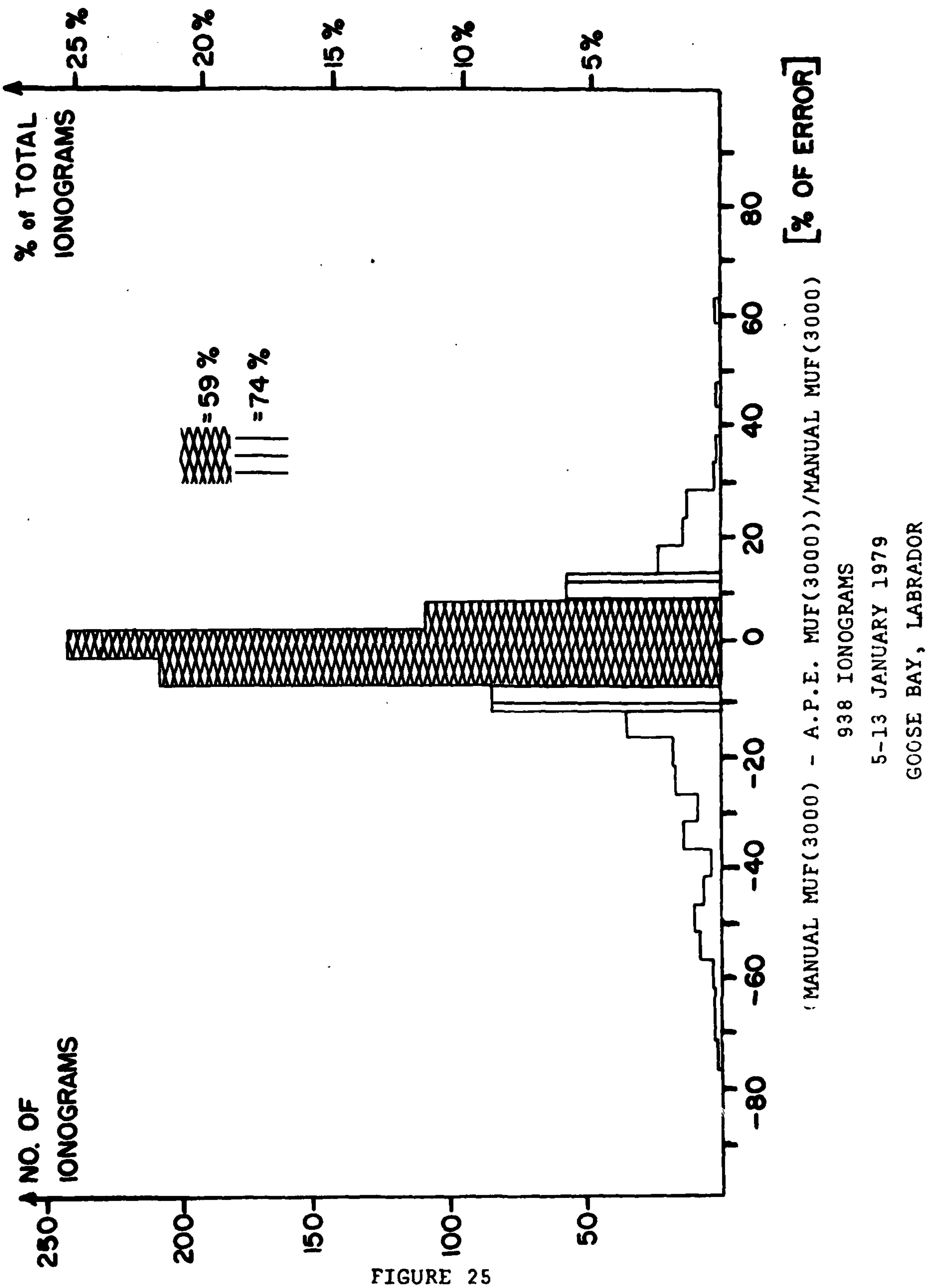
% of TOTAL IONOGRAMS
25 %
NO. OF IONOGRAMS
200
150
100
50
= 65 %
= 82 %
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
[MHz]
GEOMONITOR foF2 - A.P.E. foF2
465 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 23



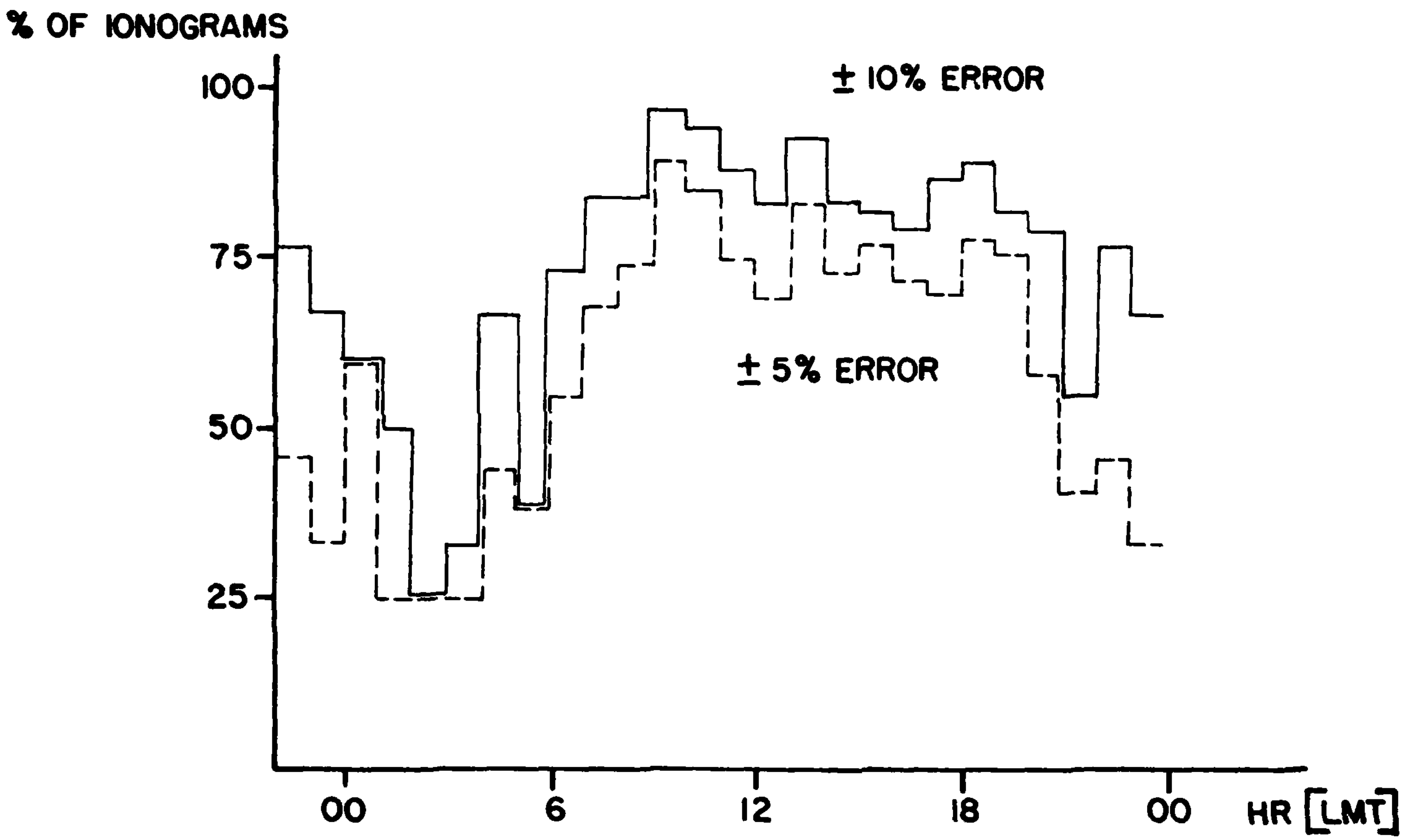
DIURNAL VARIATION OF ERROR (GEOMONITOR foF2 - A.P.E. foF2)
465 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 24



NO. OF IONOGRAMS
% of TOTAL IONOGRAMS
250
200
150
100
50
25 %
20%
15 %
10%
5%
=59 %
=74 %
-80
-60
-40
-20
0
20
40
60
80
[% OF ERROR]
(MANUAL MUF(3000) - A.P.E. MUF(3000))/MANUAL MUF(3000)
938 IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 25



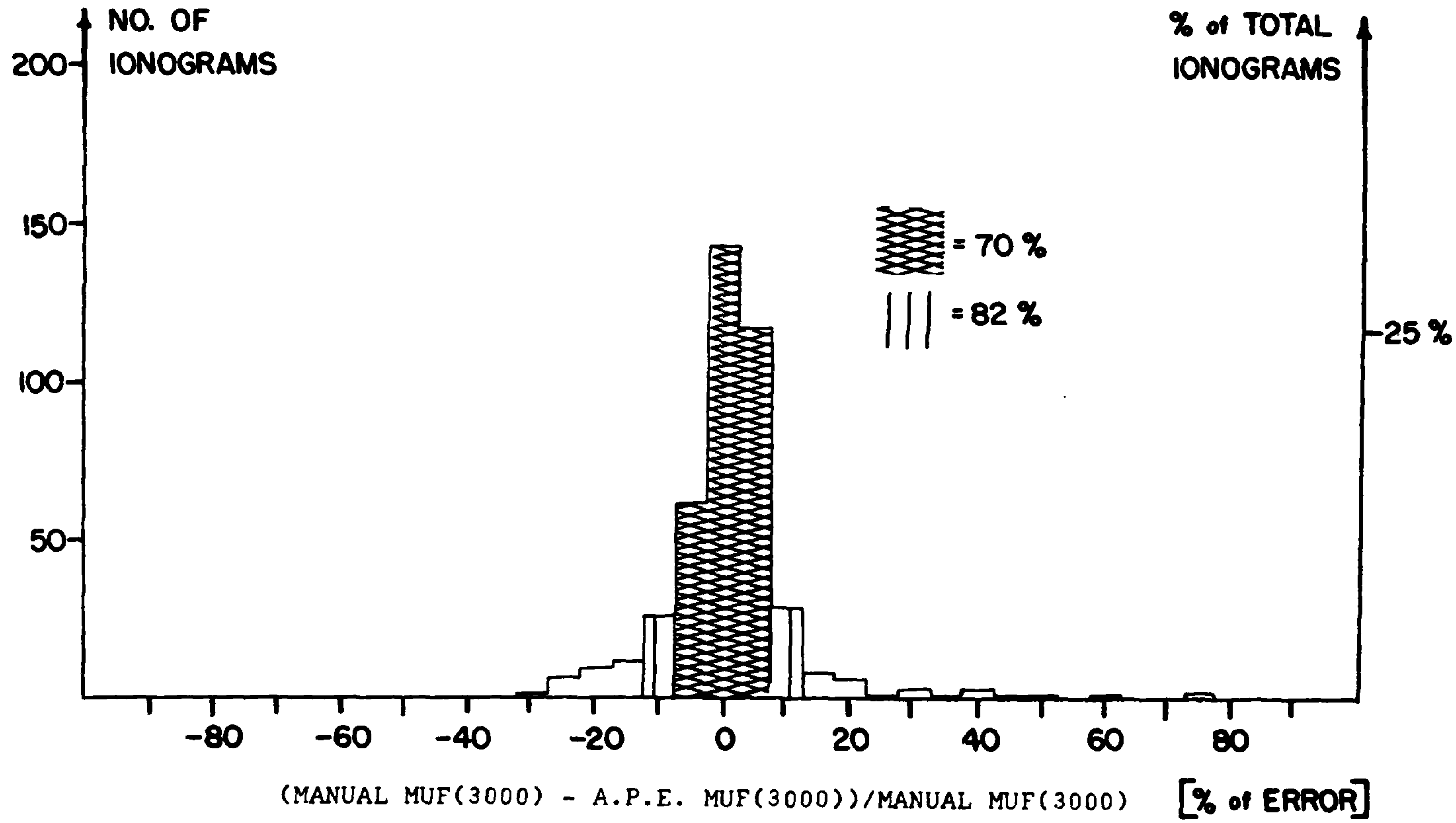
DIURNAL VARIATION OF ERROR [MANUAL MUF(3000)-A.P.E. MUF(3000))/MANUAL MUF(3000)]

938 IONOGRAMS

5-13 JANUARY 1979

GOOSE BAY, LABRADOR

FIGURE 26

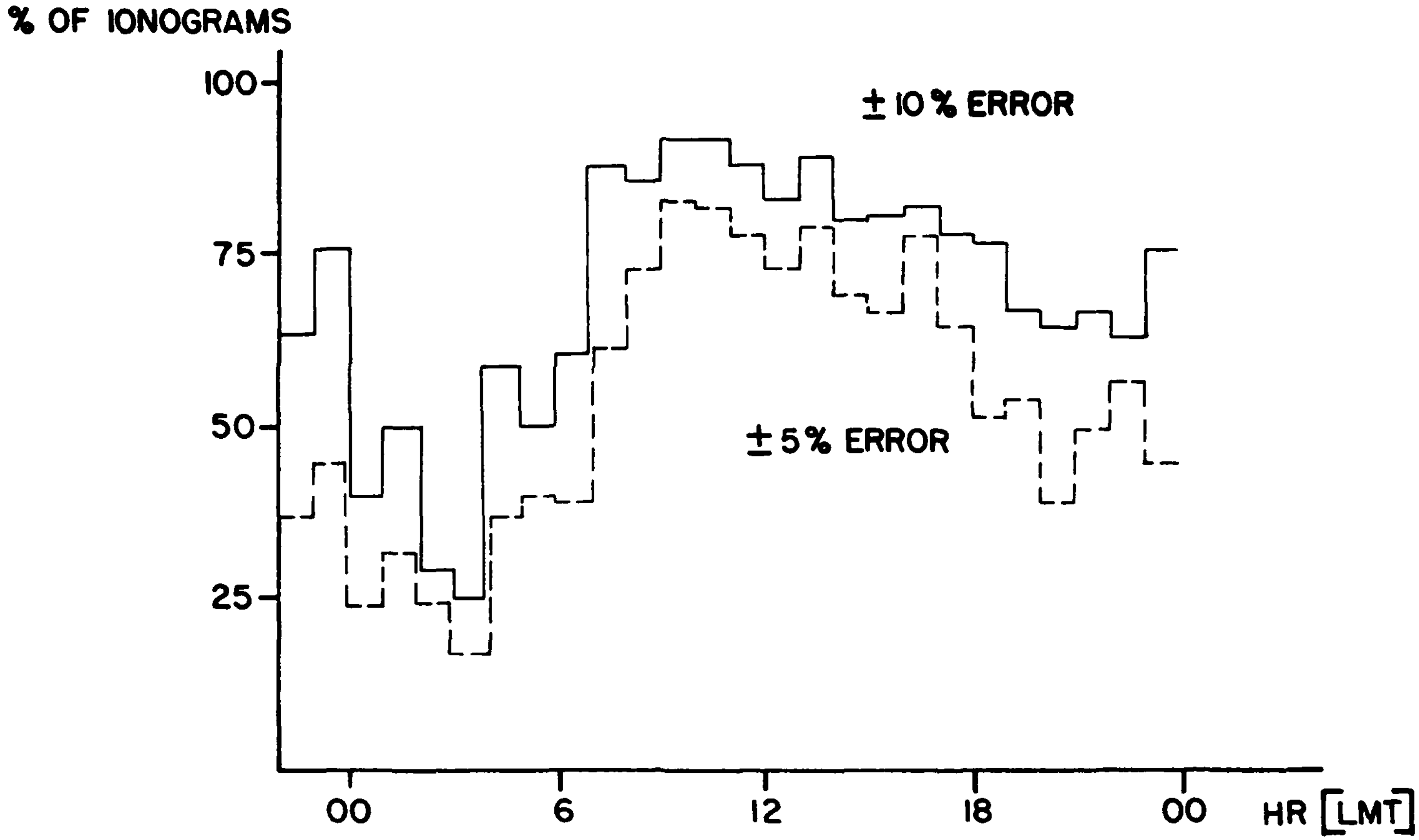


465 NON-QUALIFIED IONOGRAMS

5-13 JANUARY 1979

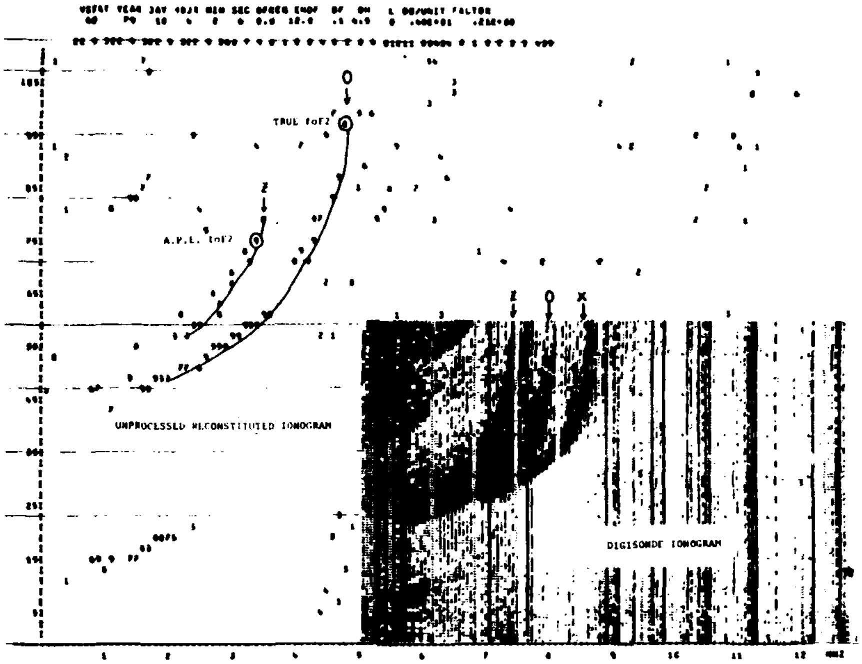
GOOSE BAY, LABRADOR

FIGURE 27

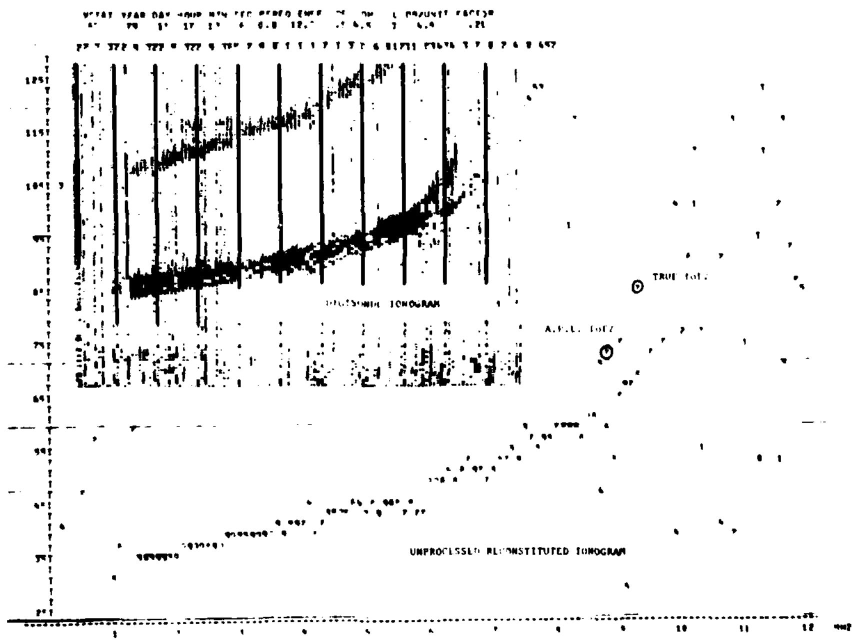


DIURNAL VARIATION OF ERROR [MANUAL MUF(3000)-A.P.E. MUF(3000))/MANUAL MUF(3000)]
465 NON-QUALIFIED IONOGRAMS
5-13 JANUARY 1979
GOOSE BAY, LABRADOR

FIGURE 28



EXAMPLE OF IONOGRAM TO SHOW THE Z COMPONENT



EXAMPLE TO SHOW THE ERROR IN APE IN DETERMINING foF2

FIGURE 29

3.3 General Features

We have shown that automatic processing of raw digital ionogram data can, in most cases, produce sensible values for the most commonly used ionospheric parameters: foF2, MUF(3000), ftEs and fmin even at an ionospheric station in the aurora zone where disturbed ionospheric conditions prevail. The parameters ftEs and fmin show very good agreement between A.P.E. and manual evaluation and we had therefore limited the discussion in this report to foF2 and MUF. It was initially intended to apply the program to undisturbed ionograms, thus testing the algorithms under very adverse conditions. Since the program is a step-by-step correction or elimination process it can easily be changed if the emphasis of the required results is shifted from inclusion of all possible cases to the limitation to undisturbed conditions or vice versa. This can be done by weighing the qualifying and descriptive letters which are produced automatically in the sequence of the program. Also adaptation of the program to data from other locations should be easy.

At this stage we can prove that the automatic analysis of ionograms generated under quiet conditions is accurate. The results obtained under disturbed conditions show no significant bias, only an increase in variance. This should not matter too much since the natural temporal and local variations under disturbed conditions are very often substantially larger than the differences in the analysis results. Thus the usefulness of the automatically scaled data is secured for practical on-line applications, local modelling and global studies.

4.0 FUTURE WORK

An improved trace identification algorithm is currently being developed intended to substitute major parts of the current three-point smoothing routine. We will further introduce a parabolic least square fitting algorithm for a more reliable foF2 determination under disturbed conditions. The next step will be to consolidate and optimize the program in respect to storage capabilities and the language requirements for implementation in an on-line microprocessor system. Although the main processes of data formatting for tape recording and hard-copy printing are already developed for other microcomputer systems (Geomonitor, ICOM), it will be necessary to develop some firmware solutions to achieve the necessary speed for producing Refined Ionograms for fast ionogram sequences.

When the A.P.E. program is implemented in hardware it will be possible to communicate these URSI parameters to a central station of a world-wide network without the assistance of an operator. The experience we have gained in producing the ICOM Ionogram Communicator (Smith et al, 1979) will enable us to create a reasonable communicator for these parameters.

Most of the restrictions and refinements built into this A.P.E. program will allow the program to automatically process ionograms generated even under severely disturbed ionospheric conditions. It is evident that a network of stations with A.P.E. programs slightly modified for their geographic location could be very useful to such agencies as the U.S. Air Weather Service. All suppositions and criteria used in this program could easily be modified for both mid-latitude and equatorial locations.

An important output of the A.P.E. program is the "refined" ionogram. This data is well suited as input into a true height program. At the Center for Atmospheric Research we have implemented into the Digisonde's Microcomputer a true height program which currently accepts data from an input terminal. This equipment was providing electron density profiles on a near real-time basis in Kwajalein, M.I., during a rocket campaign in August 1978.

Investigation into time sequence smoothing of the true height profiles should also be done to provide more reliable profiles but the refined ionogram is certainly a step forward in the automation of the electron density profiles. Certainly the scientific repercussions of this data are significant especially in correlation of vertical incidence sounder data to those of other high power radar sounders.

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A P P E N D I X   A

DEFINITION OF IONOSPHERIC PARAMETERS

APPENDIX A

DEFINITION OF IONOSPHERIC PARAMETERS

fmin: The lowest frequency at which echo traces are observed on the ionogram. The convention is that oblique or multiple echo traces are ignored and also any very weak reflections from the D region.

ftEs: The top frequency corresponding to the highest frequency at which a rather continuous Es trace is observed.

foF2: The ordinary wave critical frequency of the highest stratification in the F region.

M(3000)F: The factor obtained using the standard 3000 km transmission curve and the first order ordinary wave trace of the ionogram. MUF(3000) is the transmission curve at which the ordinary wave trace is tangential. Transmission factor M(3000) is the ratio of MUF(3000)F and foF2.

A P P E N D I X B

QUALIFYING OF READINGS

APPENDIX B

QUALIFYING OF READINGS

If there is any doubt or further explanation is needed to clarify a reading, qualifying and descriptive letters are added to the numerical value. Qualifying letters cannot exist without descriptive letters, yet the descriptive letters may be used alone. In the case of a probable error > 15% just a descriptive letter is used with no numerical reading.

Qualifying Letters

With respect to the actual reading the real value would be:

D - greater than by 5% to 10%

E - less than by 5% to 10%

I - interpolated with 5% to 10% accuracy.

J - derived from X component

U - approximately 2% < error < 5%

If the error is < 2% no qualifier is necessary.

Descriptive Letters

Measurements influenced or impossible because of:

A - blanketing

B - absorption

C - technical difficulties

D - upper frequency limit

E - lower frequency limit

F - spread

G - low ionization density

H - stratification

K - night E

L - no cusp

M - O and X not distinguishable

O - ordinary component

Q - range spread (usually use F)

R - attenuation near maximum frequency

S - radio interference

T - derived from other readings

V - forked trace

W - outside height range

X - derived from X trace

Y - F lacuna

Z - derived from Z trace

A P P E N D I X   C

h' VS M(3000) DERIVED FROM URSI MUF(3000) DATA

PRECEDING PAGE BLANK-NOT FILMED

H' [KM]	M(3000)	H' [KM]	M(3000)	H' [KM]	M(3000)	H' [KM]	M(3000)
181.50	4.76	296.25	3.68	411.00	3.03	525.75	2.60
183.75	4.73	298.50	3.66	413.25	3.02	528.00	2.60
186.00	4.71	300.75	3.64	415.50	3.01	530.25	2.59
188.25	4.68	303.00	3.63	417.75	3.00	532.50	2.58
190.50	4.66	305.25	3.61	420.00	2.99	534.75	2.57
192.75	4.63	307.50	3.60	422.25	2.98	537.00	2.57
195.00	4.61	309.75	3.58	424.50	2.98	539.25	2.56
197.25	4.58	312.00	3.57	426.75	2.97	541.50	2.55
199.50	4.56	314.25	3.55	429.00	2.96	543.75	2.55
201.75	4.53	316.50	3.54	431.25	2.95	546.00	2.54
204.00	4.51	318.75	3.52	433.50	2.94	548.25	2.53
206.25	4.48	321.00	3.51	435.75	2.93	550.50	2.53
208.50	4.46	323.25	3.49	438.00	2.92	552.75	2.52
210.75	4.43	325.50	3.48	440.25	2.91	555.00	2.51
213.00	4.41	327.75	3.46	442.50	2.90	557.25	2.51
215.25	4.39	330.00	3.45	444.75	2.89	559.50	2.50
217.50	4.36	332.25	3.43	447.00	2.89	561.75	2.49
219.75	4.34	334.50	3.42	449.25	2.88	564.00	2.49
222.00	4.32	336.75	3.41	451.50	2.87	566.25	2.48
224.25	4.30	339.00	3.39	453.75	2.86	568.50	2.48
226.50	4.27	341.25	3.38	456.00	2.85	570.75	2.47
228.75	4.25	343.50	3.37	458.25	2.84	573.00	2.46
231.00	4.23	345.75	3.35	460.50	2.83	575.25	2.46
233.25	4.21	348.00	3.34	462.75	2.83	577.50	2.45
235.50	4.18	350.25	3.33	465.00	2.82	579.75	2.45
237.75	4.16	352.50	3.32	467.25	2.81	582.00	2.44
240.00	4.14	354.75	3.30	469.50	2.80	584.25	2.44
242.25	4.12	357.00	3.29	471.75	2.79	586.50	2.43
244.50	4.10	359.25	3.28	474.00	2.78	588.75	2.43
246.75	4.08	361.50	3.27	476.25	2.78	591.00	2.42
249.00	4.06	363.75	3.26	478.50	2.77	593.25	2.41
251.25	4.04	366.00	3.24	480.75	2.76	595.50	2.41
253.50	4.02	368.25	3.23	483.00	2.75	597.75	2.40
255.75	4.00	370.50	3.22	485.25	2.74	600.00	2.40
258.00	3.98	372.75	3.21	487.50	2.73	602.25	2.40
260.25	3.96	375.00	3.20	489.75	2.73	604.50	2.39
262.50	3.94	377.25	3.19	492.00	2.72	606.75	2.39
264.75	3.92	379.50	3.18	494.25	2.71	609.00	2.38
267.00	3.90	381.75	3.16	496.50	2.70	611.25	2.38
269.25	3.88	384.00	3.15	498.75	2.69	613.50	2.37
271.50	3.87	386.25	3.14	501.00	2.69	615.75	2.37
273.75	3.85	388.50	3.13	503.25	2.68	618.00	2.36
276.00	3.83	390.75	3.12	505.50	2.67	620.25	2.36
278.25	3.81	393.00	3.11	507.75	2.66	622.50	2.35
280.50	3.79	395.25	3.10	510.00	2.66	624.75	2.35
282.75	3.78	397.50	3.09	512.25	2.65	627.00	2.34
285.00	3.76	399.75	3.08	514.50	2.64	629.25	2.34
287.25	3.74	402.00	3.07	516.75	2.63	631.50	2.33
289.50	3.73	404.25	3.06	519.00	2.63	633.75	2.33
291.75	3.71	406.50	3.05	521.25	2.62	636.00	2.32
294.00	3.69	408.75	3.04	523.50	2.61		